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(12) **United States Patent**
Maheshwari et al.

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(45) **Date of Patent: Dec. 29, 2015**

(54) **POWDER DISPENSER MODULES AND POWDER DISPENSER ASSEMBLIES**

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(73) Assignee: **MannKind Corporation**, Valencia, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1238 days.

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(2), (4) Date: **Mar. 30, 2011**

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PCT Pub. Date: **Feb. 11, 2010**

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(51) **Int. Cl.**
B65B 1/20 (2006.01)
B65B 1/46 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ... ***B65B 1/46*** (2013.01); ***B65B 1/12*** (2013.01); ***B65B 1/30*** (2013.01); ***B65B 1/32*** (2013.01); ***B65B 37/14*** (2013.01); ***B65B 57/145*** (2013.01)

(58) **Field of Classification Search**
CPC B65B 37/10; B65B 1/12; B65B 1/30; B65B 1/32; B65B 1/46; B65B 37/14; B65B 57/145
USPC 141/71–72, 256, 12; 222/410, 412
See application file for complete search history.

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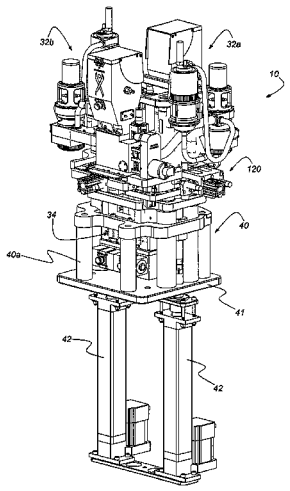
(74) *Attorney, Agent, or Firm* — Wolf, Greenfield & Sacks, P.C.

(57) **ABSTRACT**

A powder dispenser module (**54**) includes a housing (**150**) that defines a conduit connecting a powder inlet and a powder outlet, a feed wand (**160**) to move powder through the conduit from the powder inlet to the powder outlet, the feed wand (**200**) including a lower feed element (**230**) coupled to a first drive shaft and an upper feed element (**220**) coupled to a second drive shaft, a first actuator coupled to the first drive shaft to rotate the lower feed element (**230**), and a second actuator coupled to the second drive shaft to rotate the upper feed element (**220**). In other embodiments, the feed wand (**200**) includes a shaft having a fluidizing element and an actuator produces oscillatory movement of the feed wand during dispensing of powder. Dispenser module arrays include one or a few rows of dispenser modules.

17 Claims, 24 Drawing Sheets



(51) **Int. Cl.**

B65B 1/12	(2006.01)
B65B 1/30	(2006.01)
B65B 1/32	(2006.01)
B65B 37/14	(2006.01)
B65B 57/14	(2006.01)

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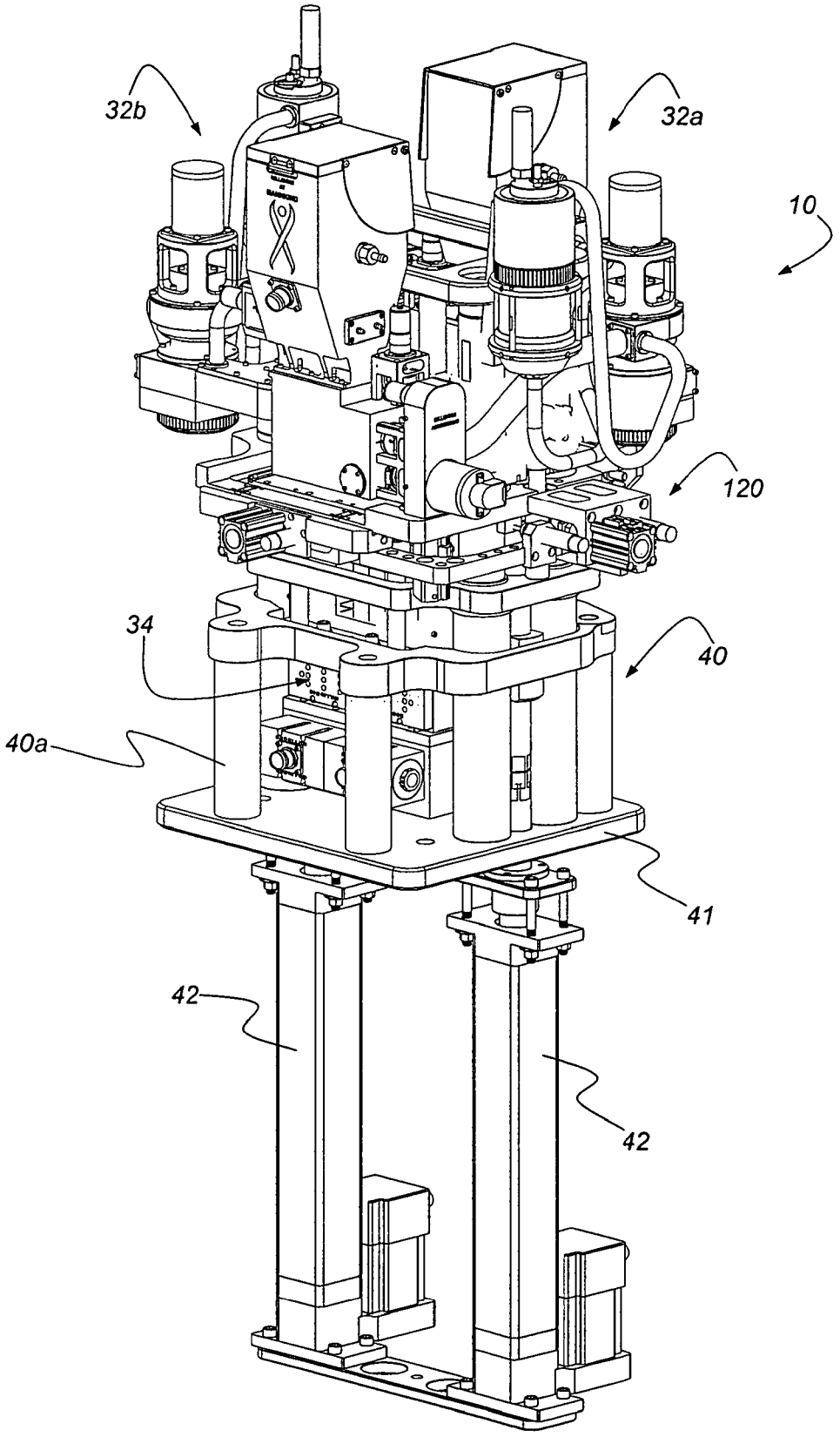


FIG. 1

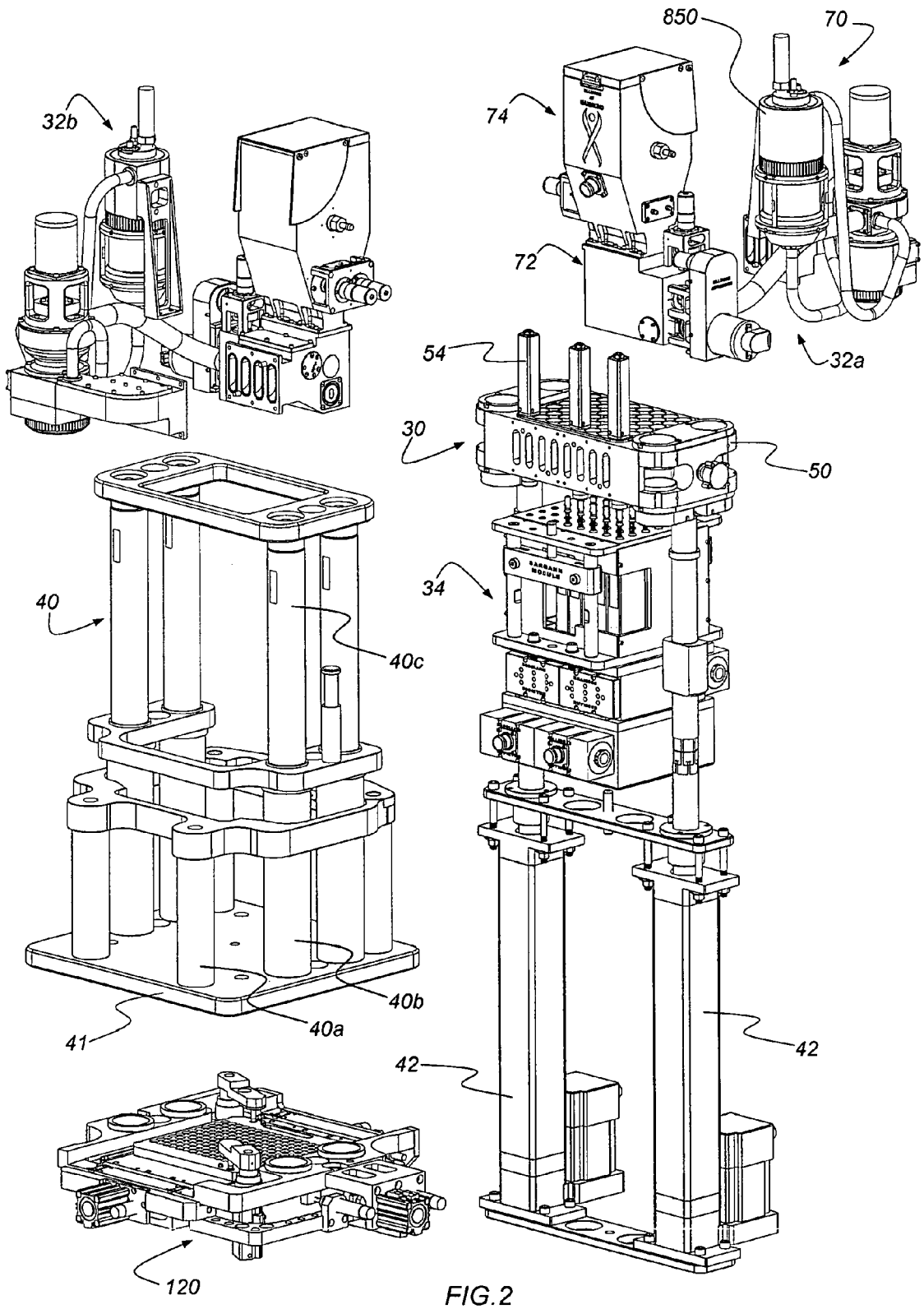


FIG. 2

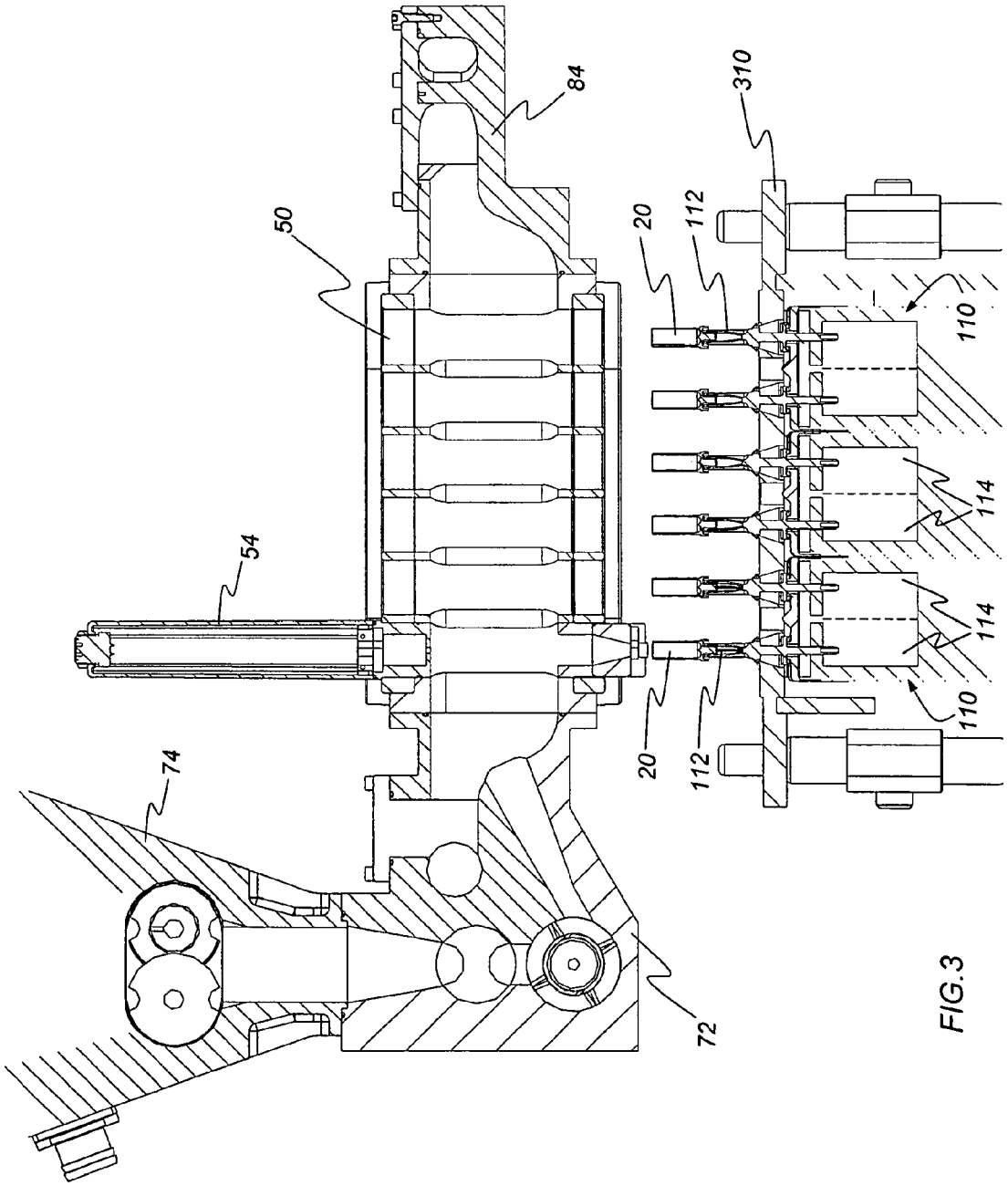
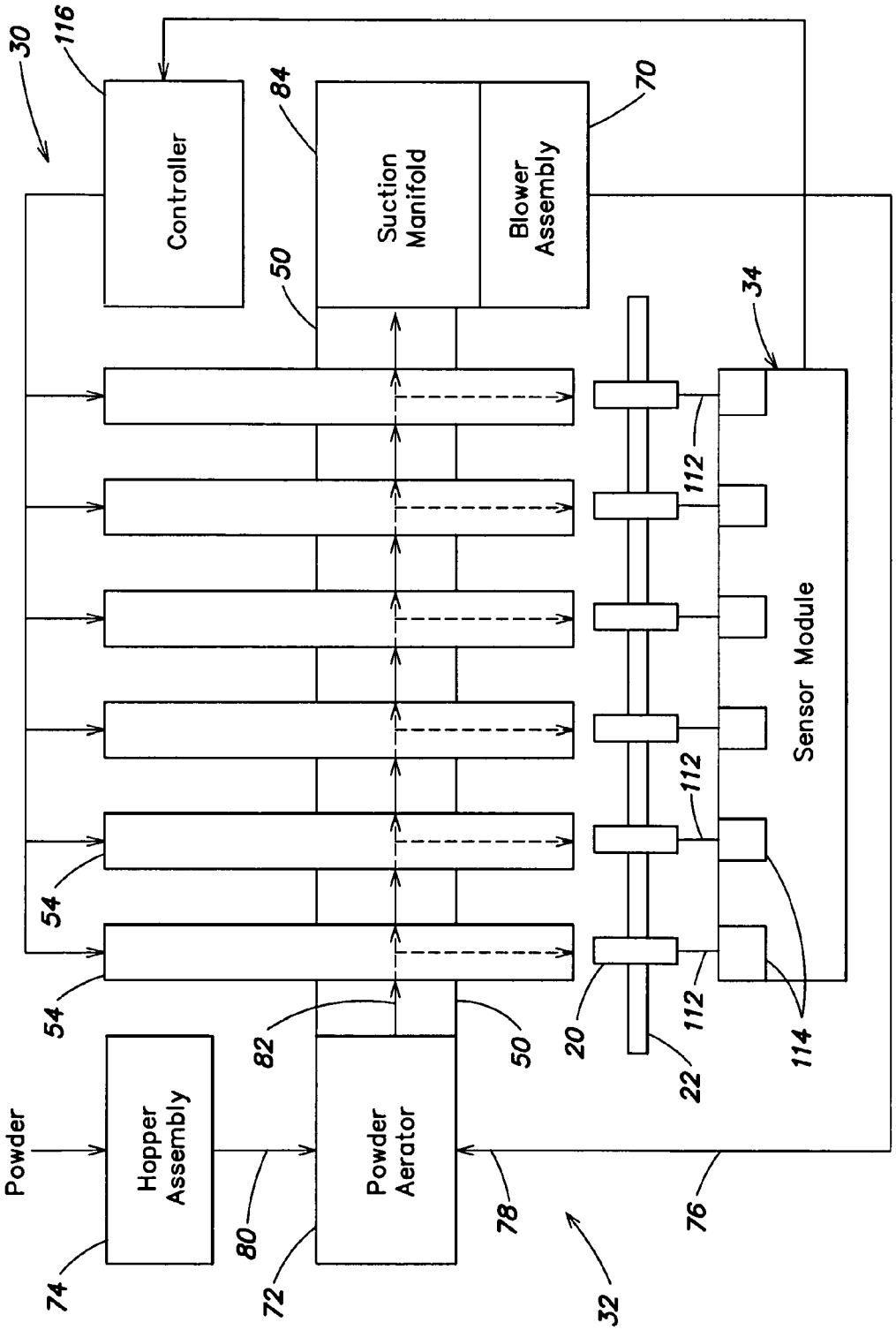


FIG.3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116
Controller
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Suction Manifold
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Blower Assembly
50
34
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Sensor Module
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82
20
22
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Powder
Hopper Assembly
Powder Aerator
74
80
72
78
76
32

FIG. 3A

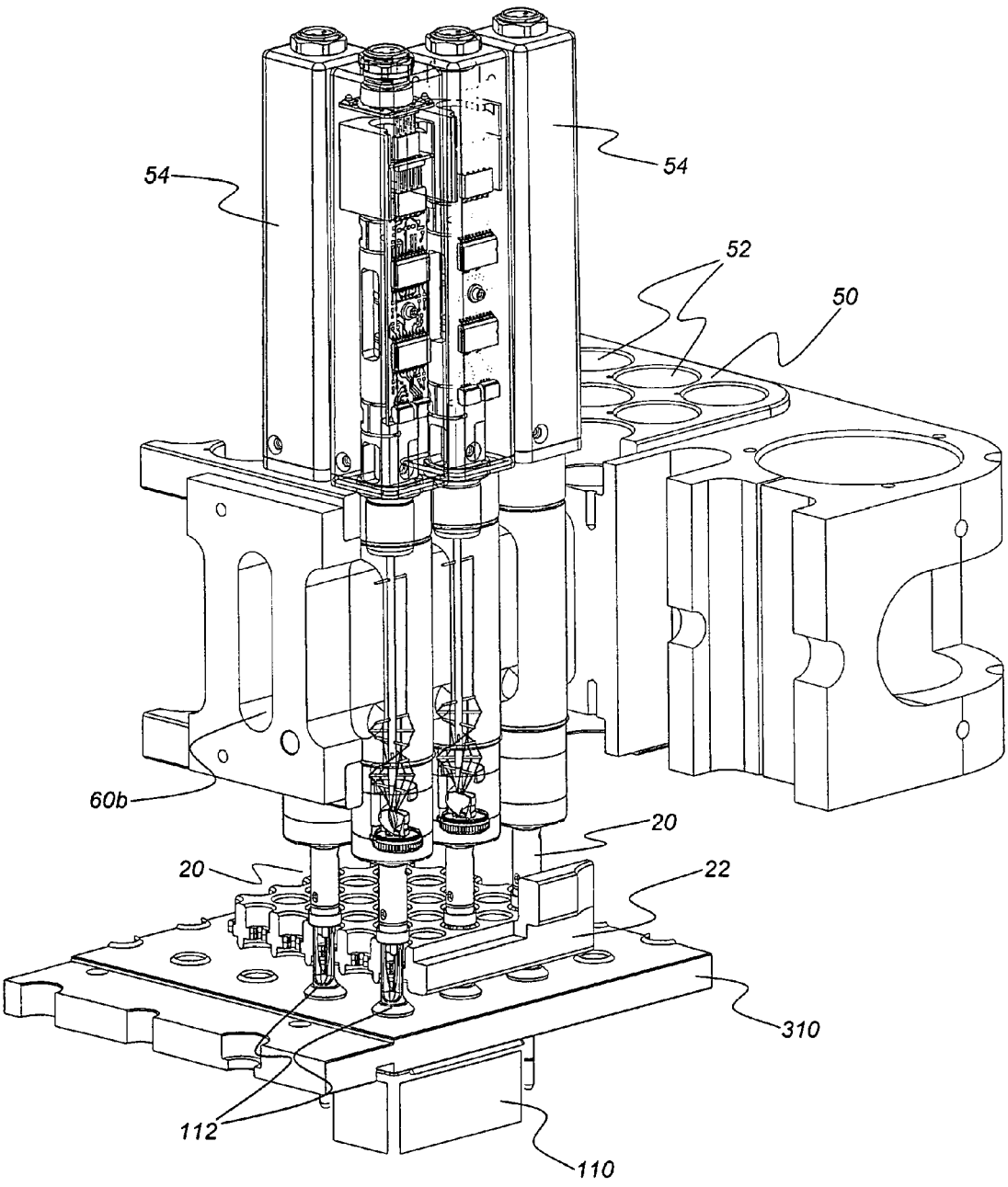


FIG.4

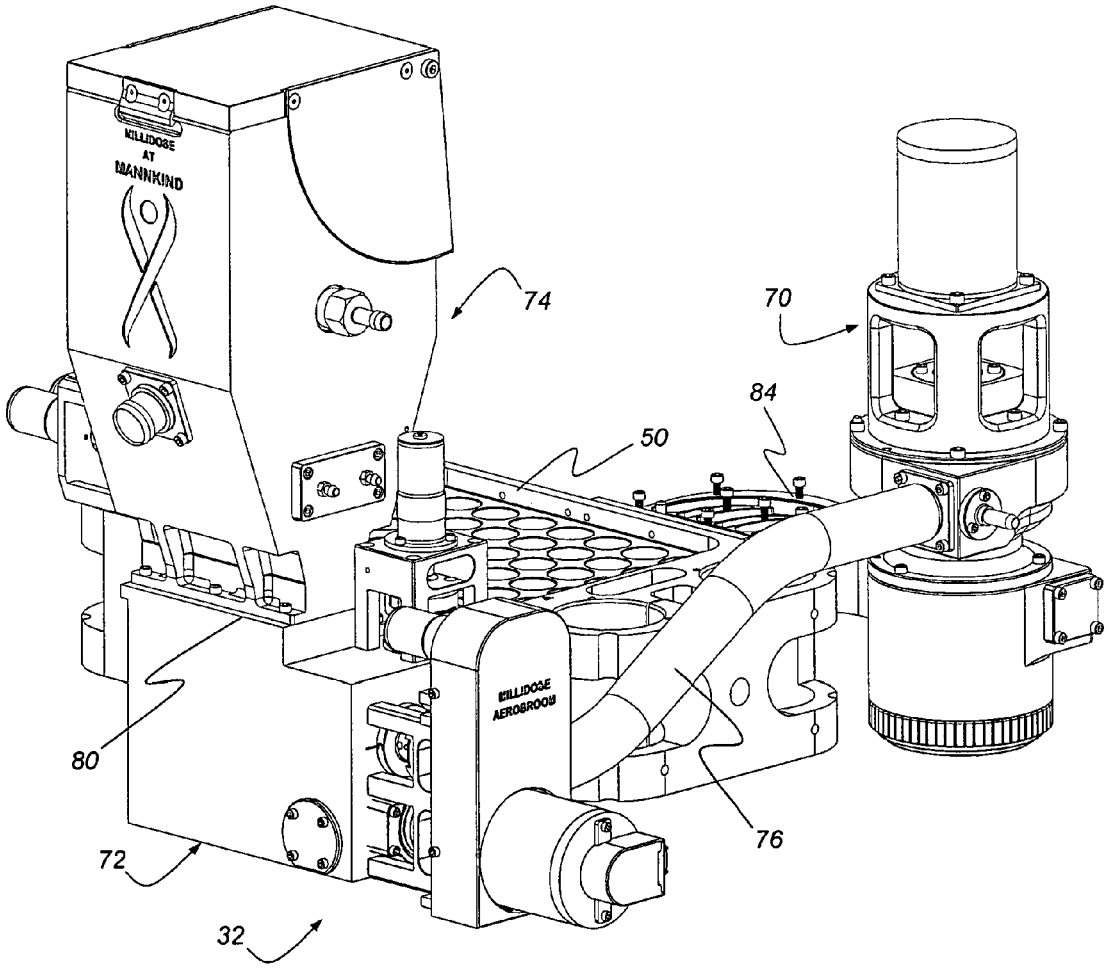


FIG.5

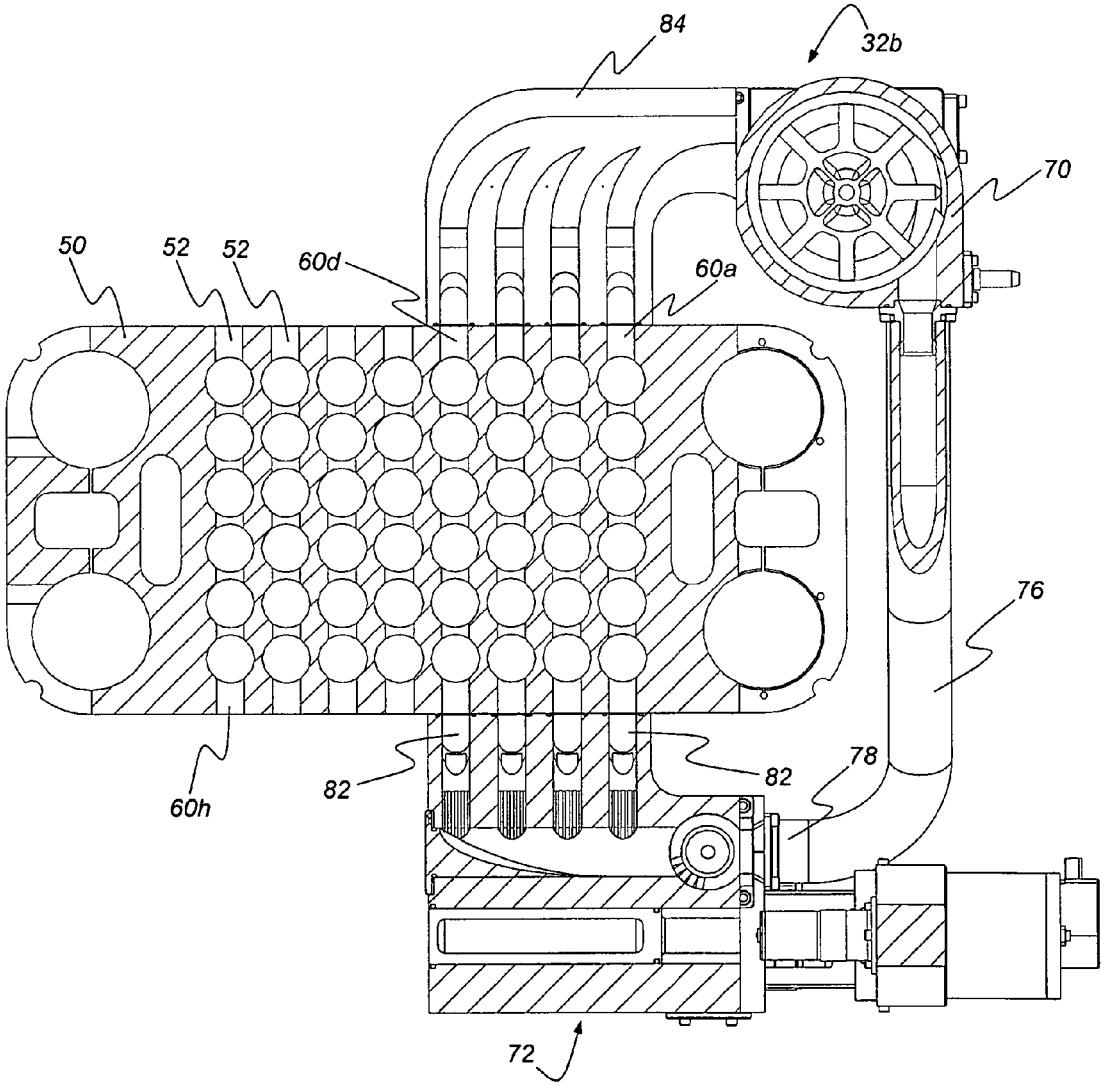


FIG.6

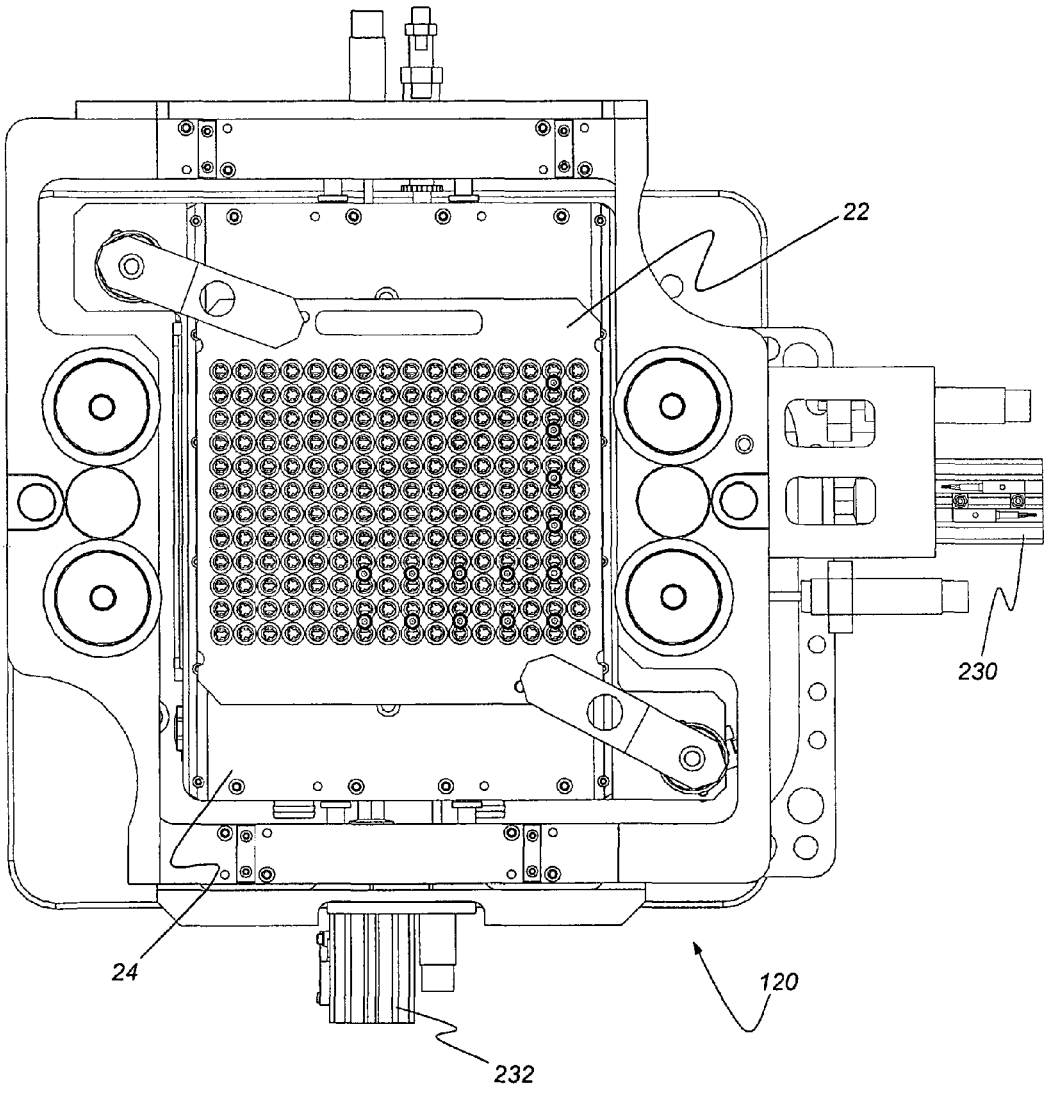


FIG.7

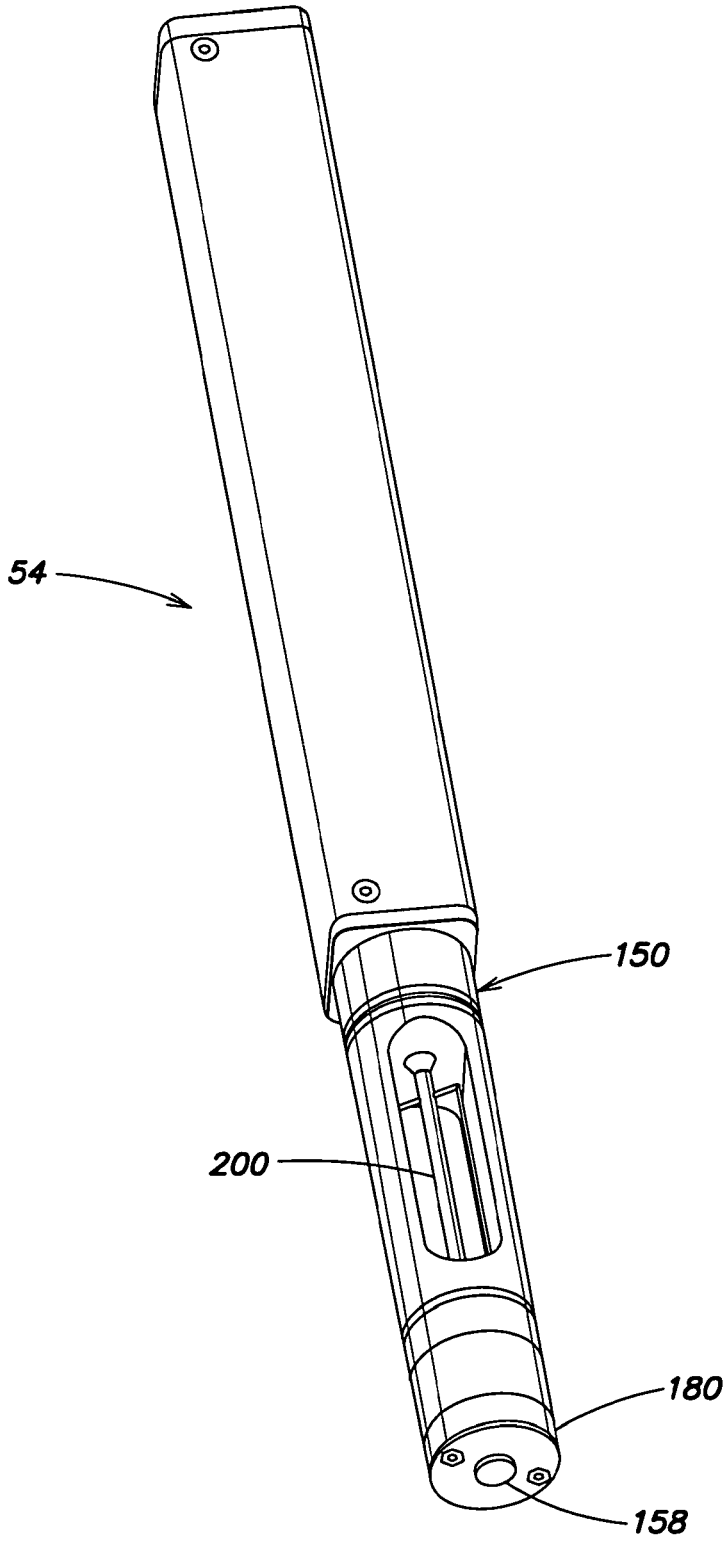


FIG. 8

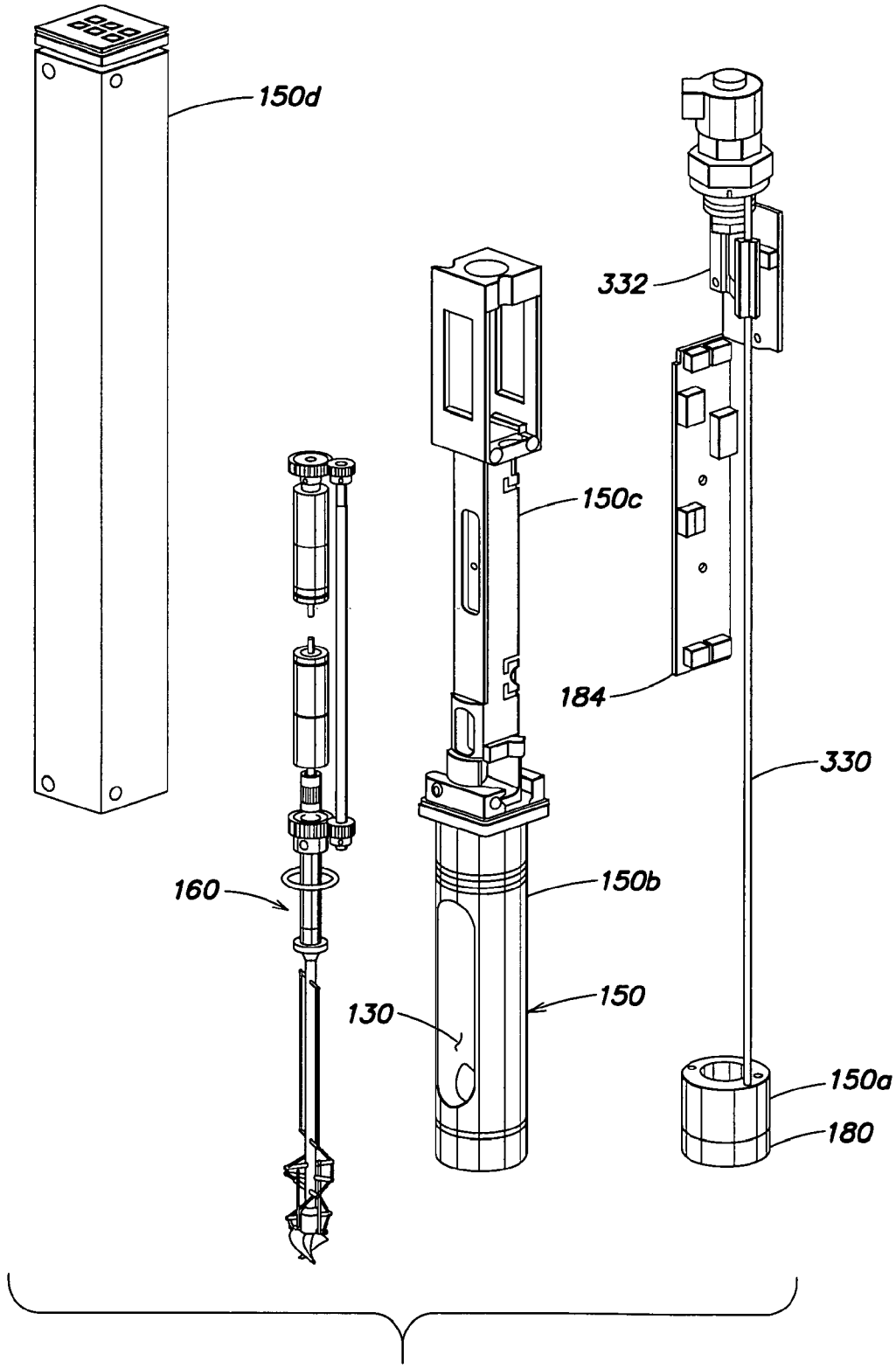


FIG. 9

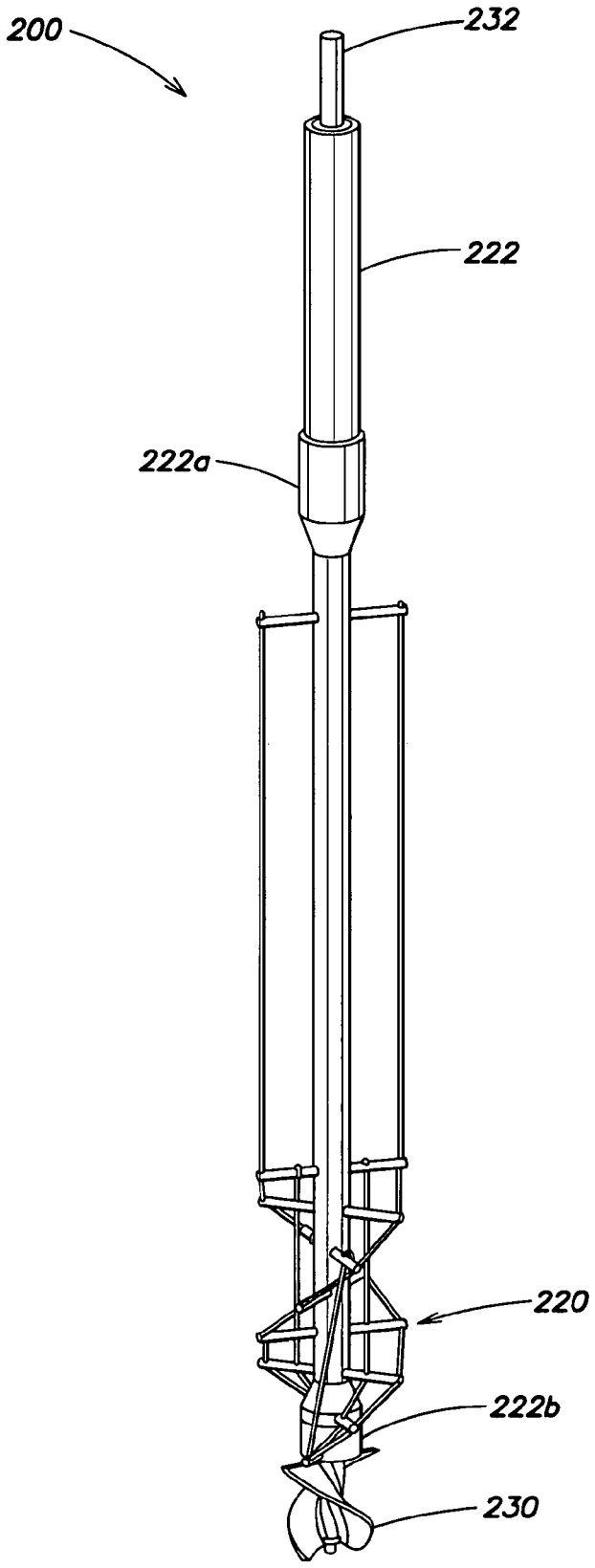
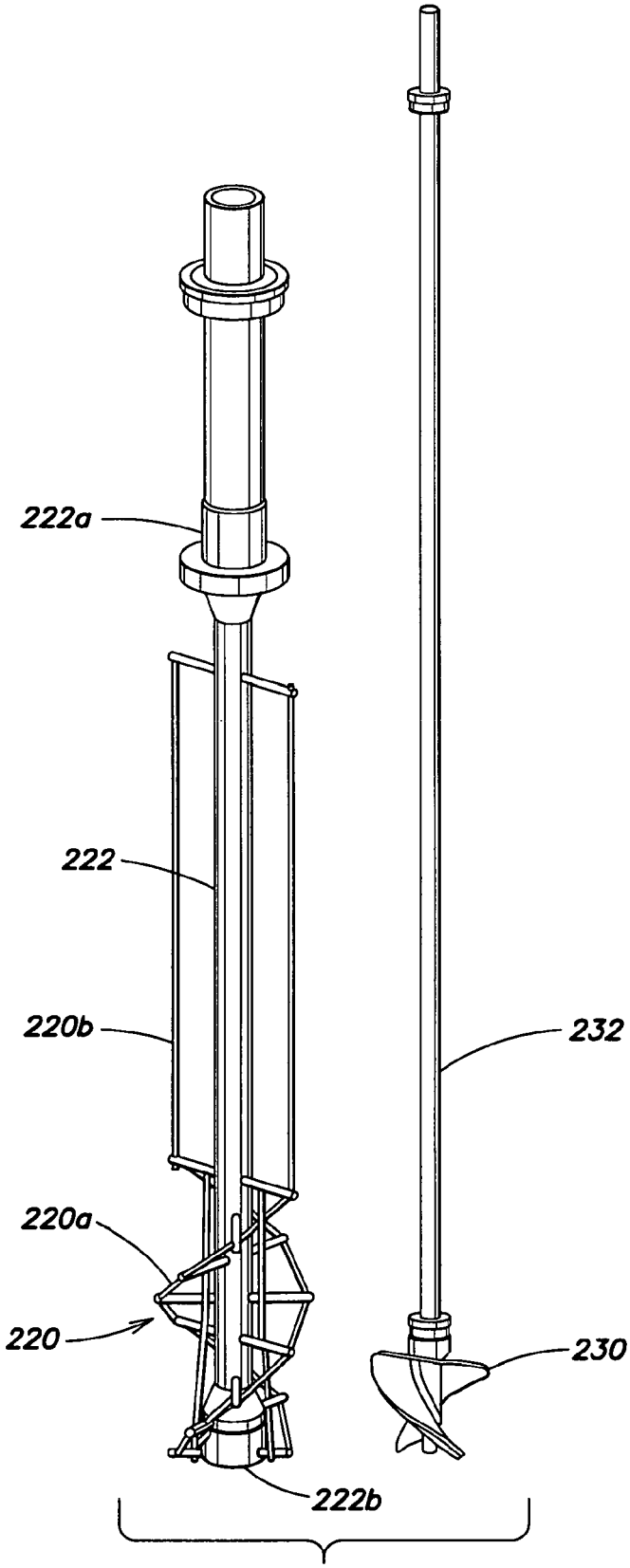


FIG. 10



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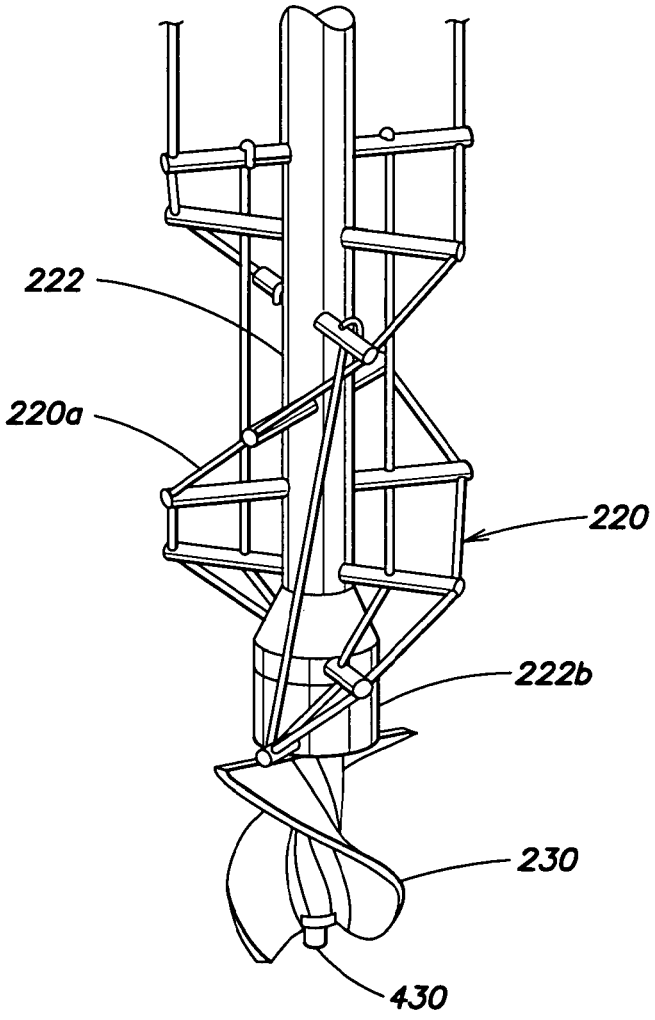


FIG. 12

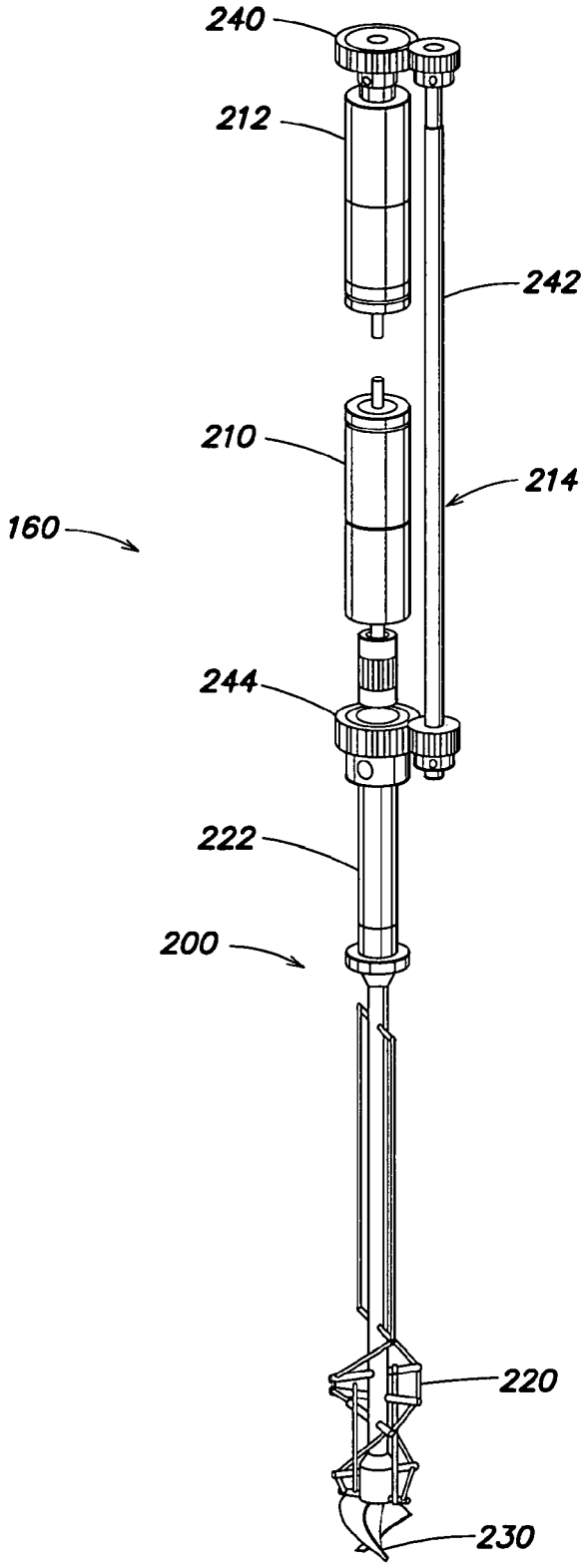


FIG. 13

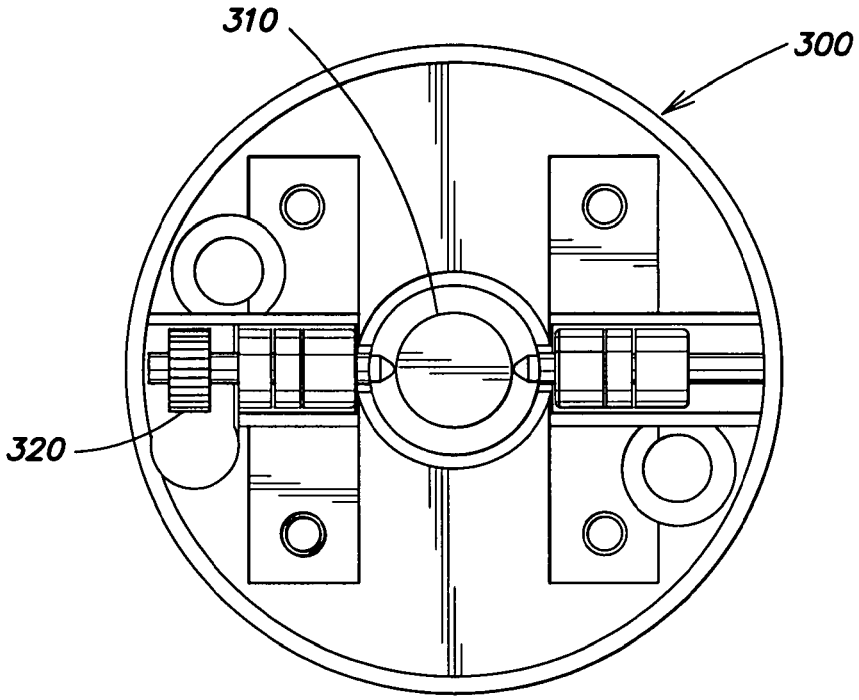


FIG. 14A

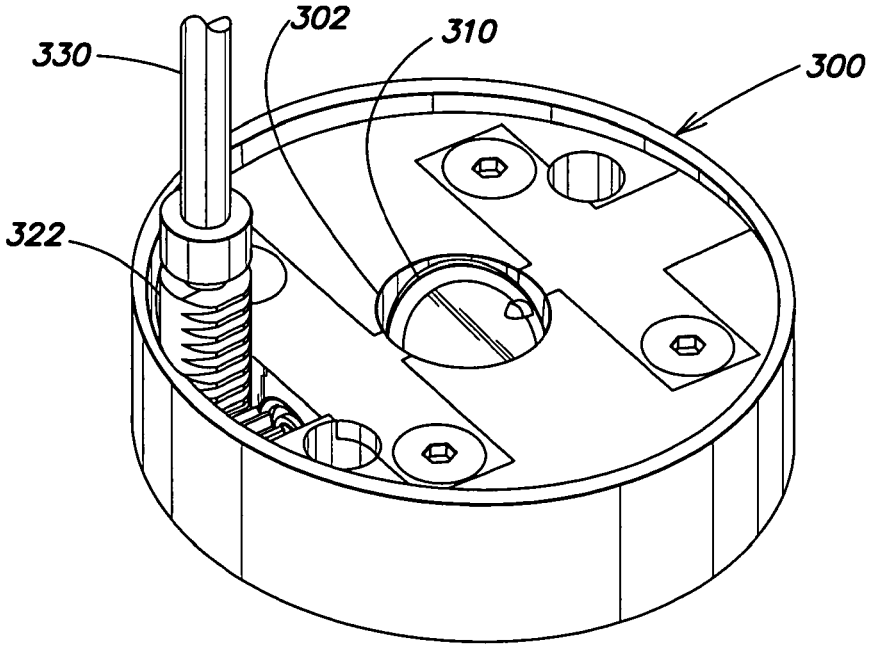


FIG. 14B

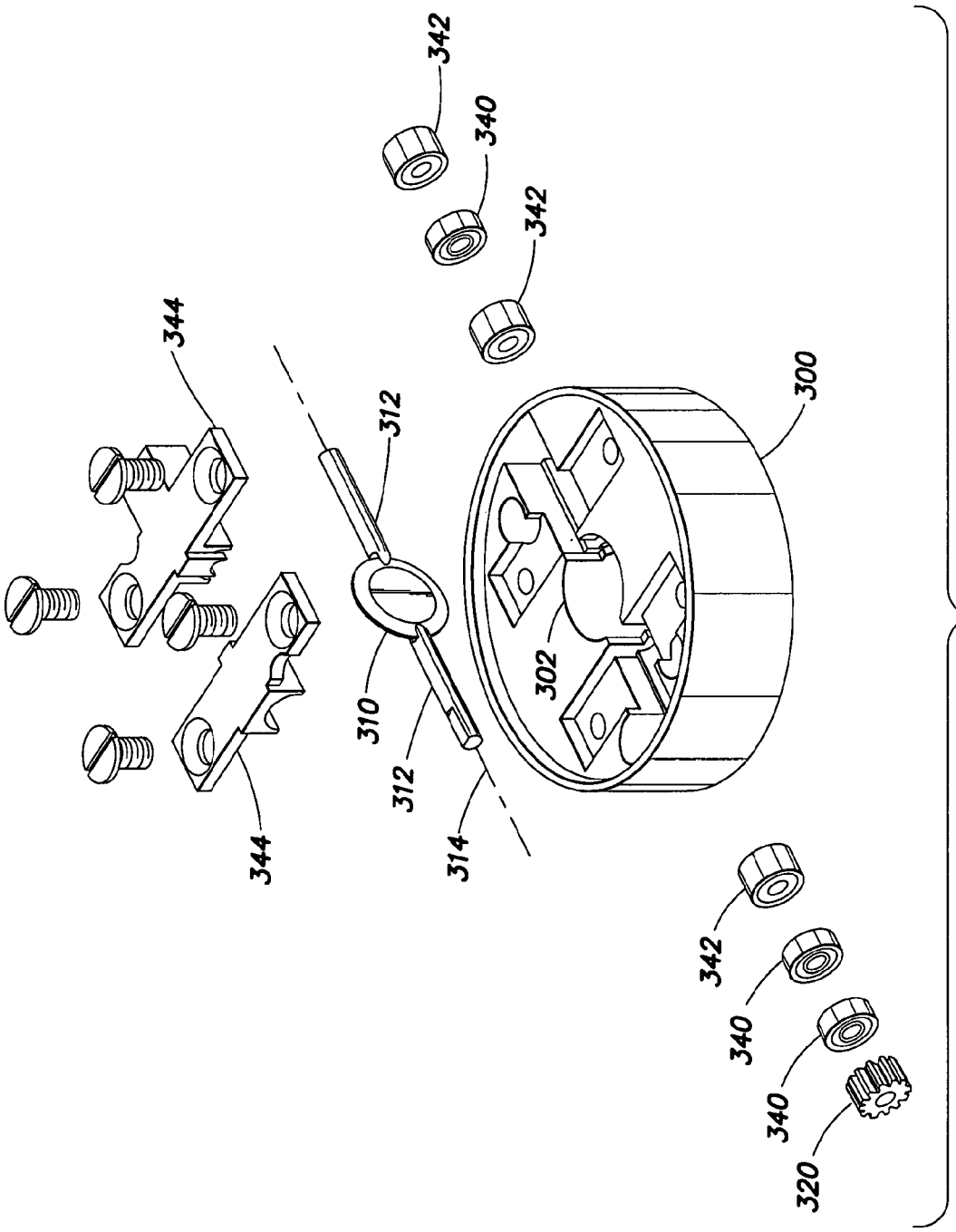


FIG. 15

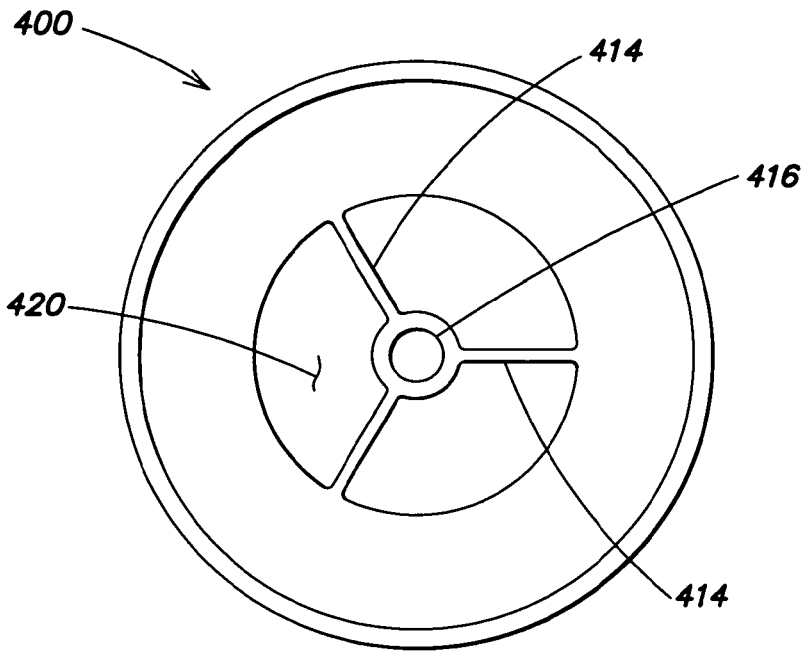


FIG. 16A

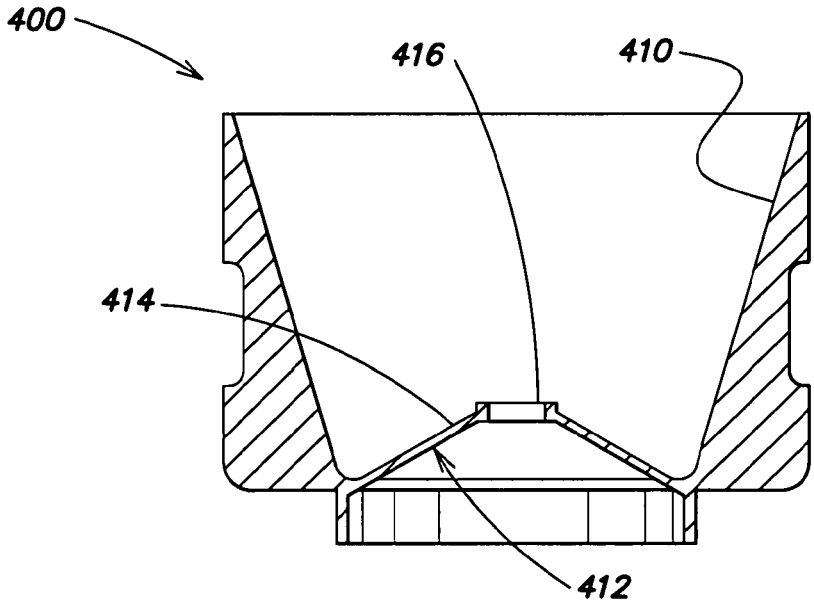


FIG. 16B

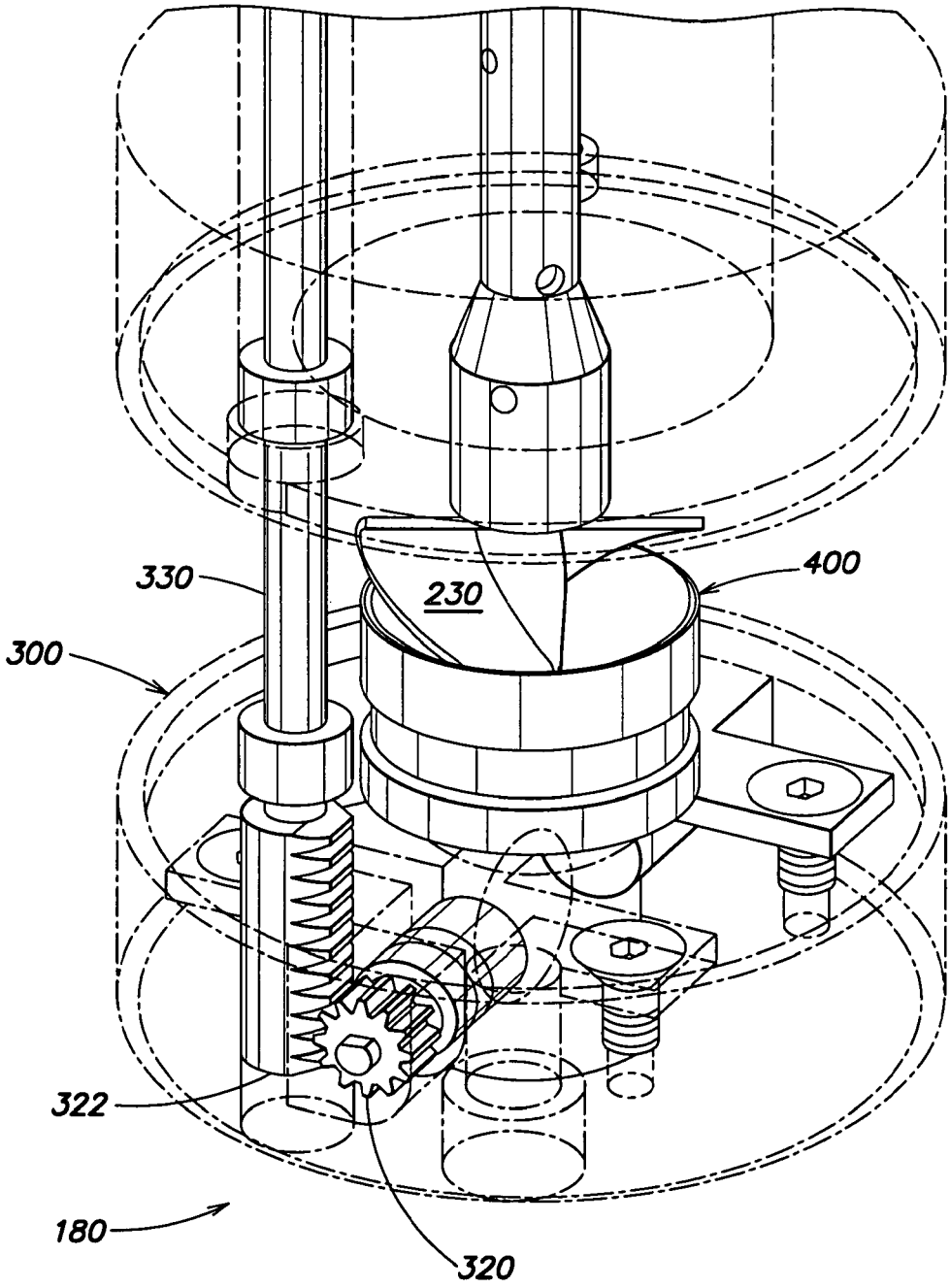


FIG. 17

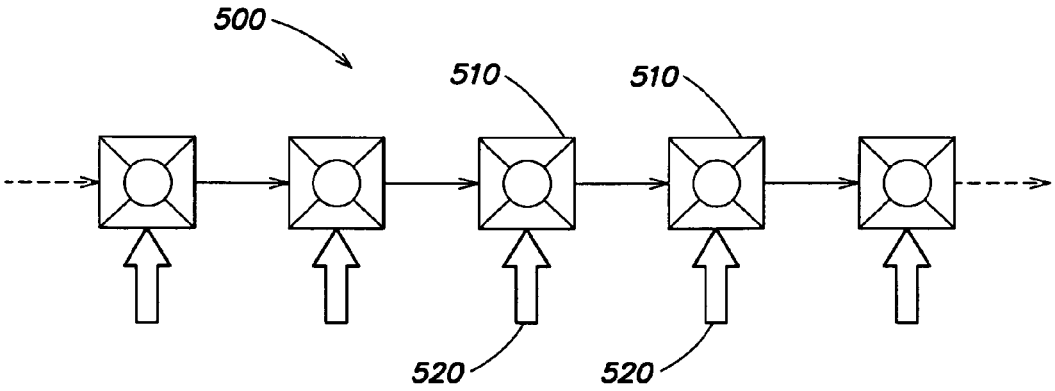


FIG. 18

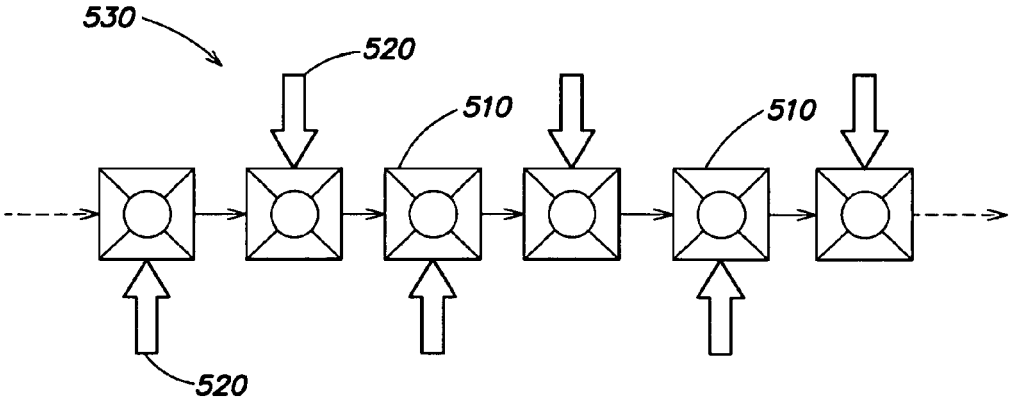


FIG. 19

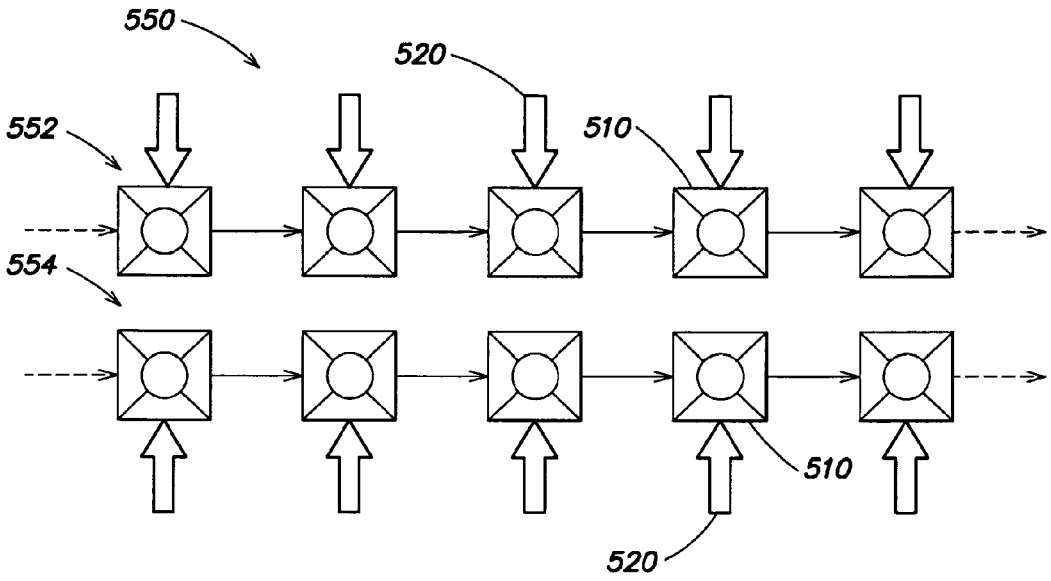


FIG. 20

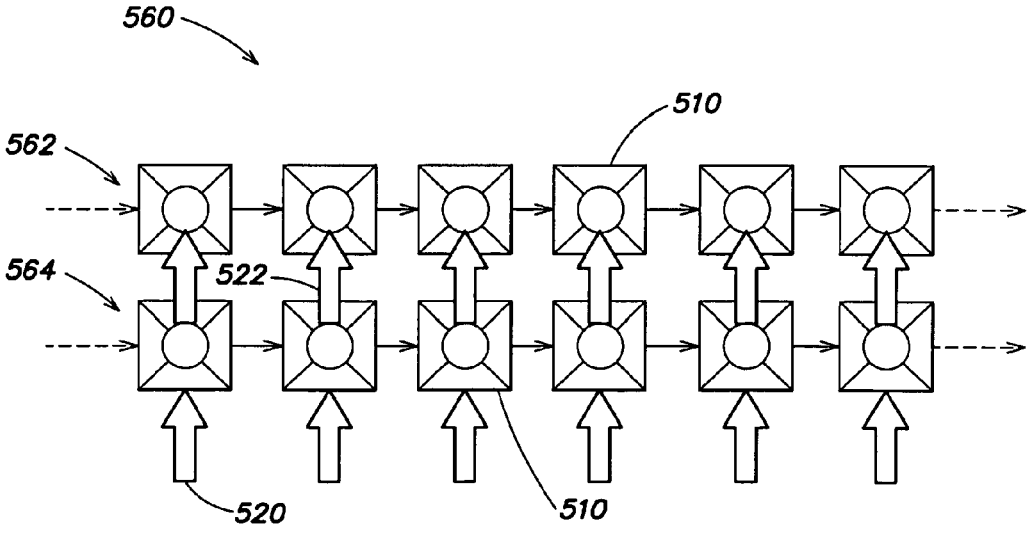


FIG. 21

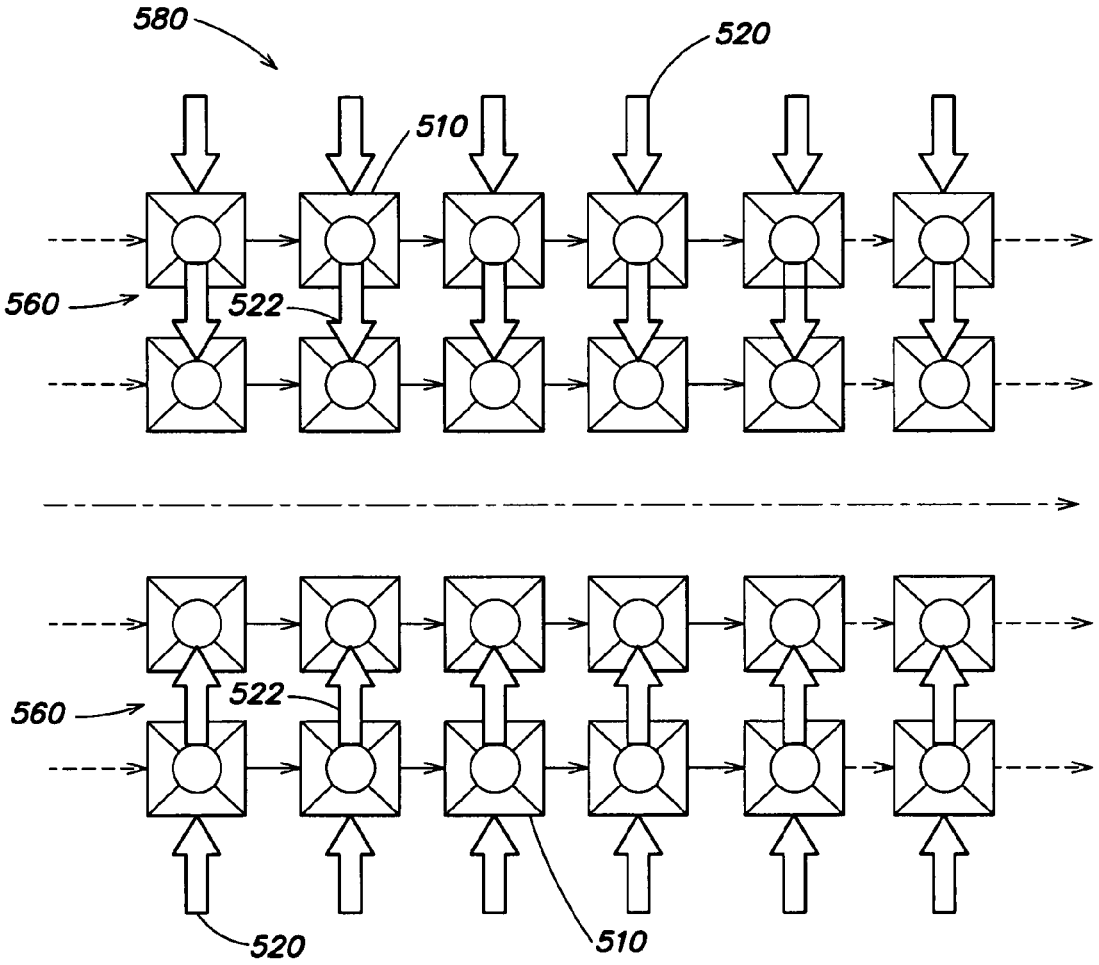


FIG. 22

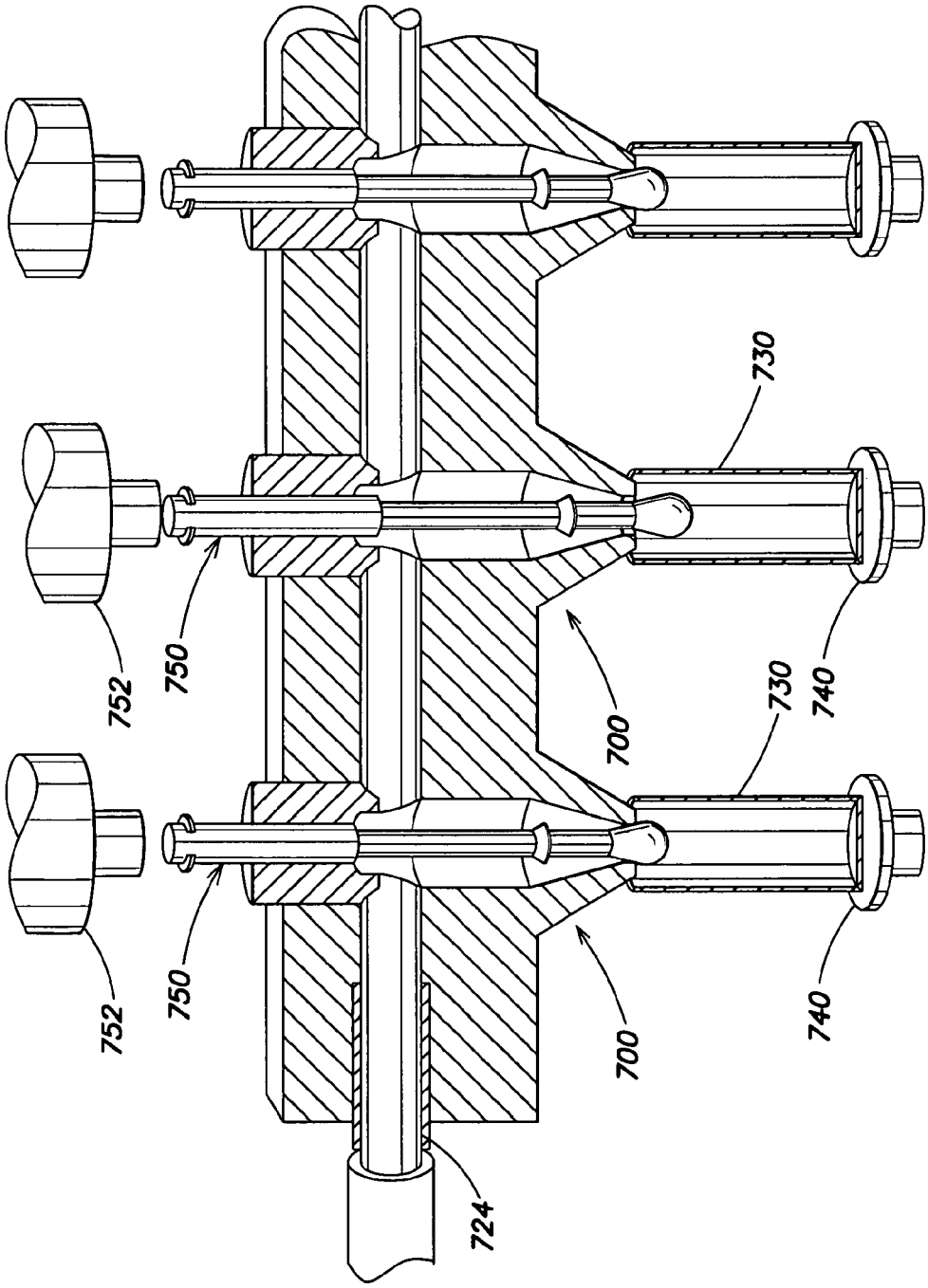
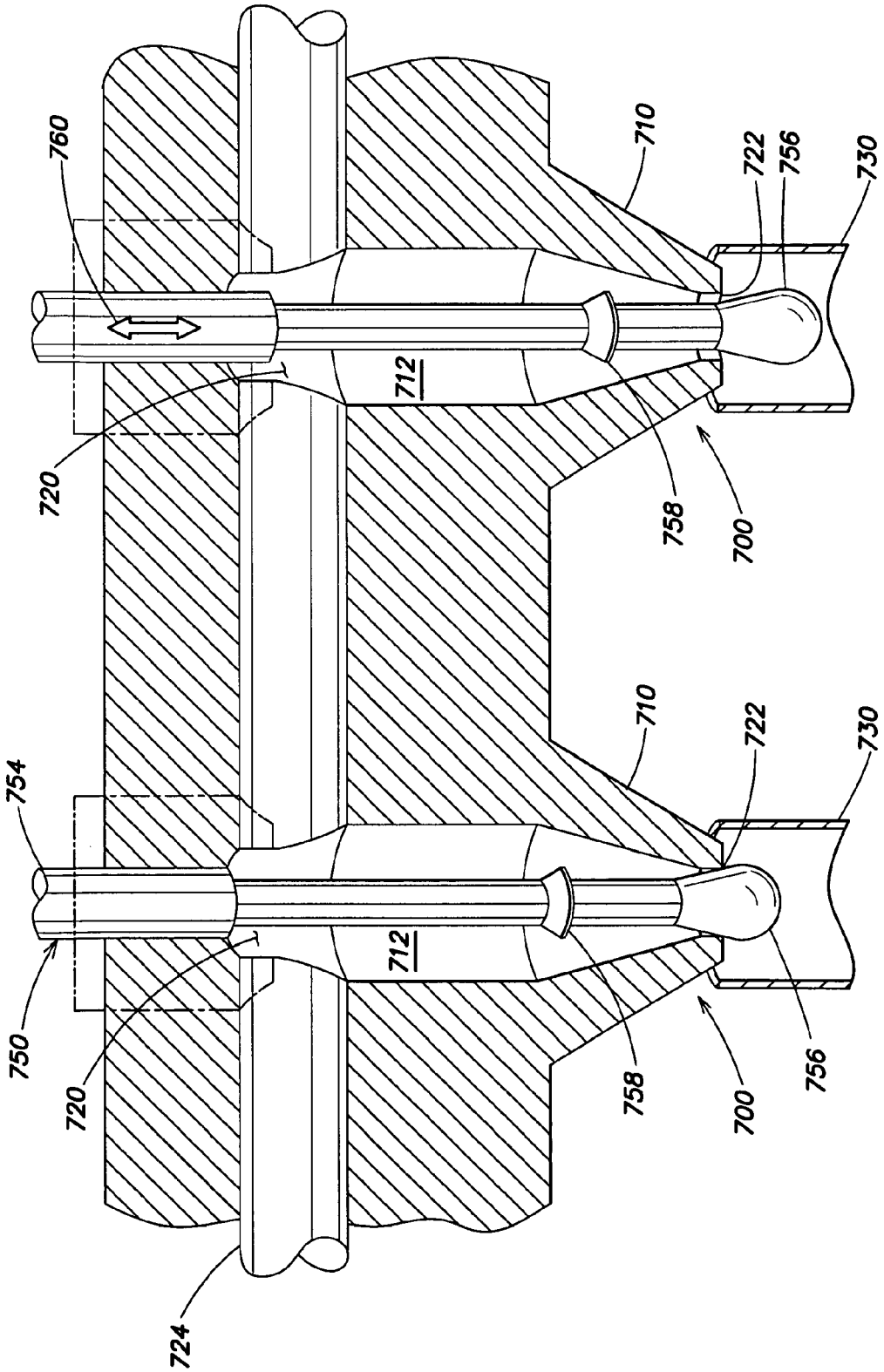


FIG. 23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700
756
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FIG. 24

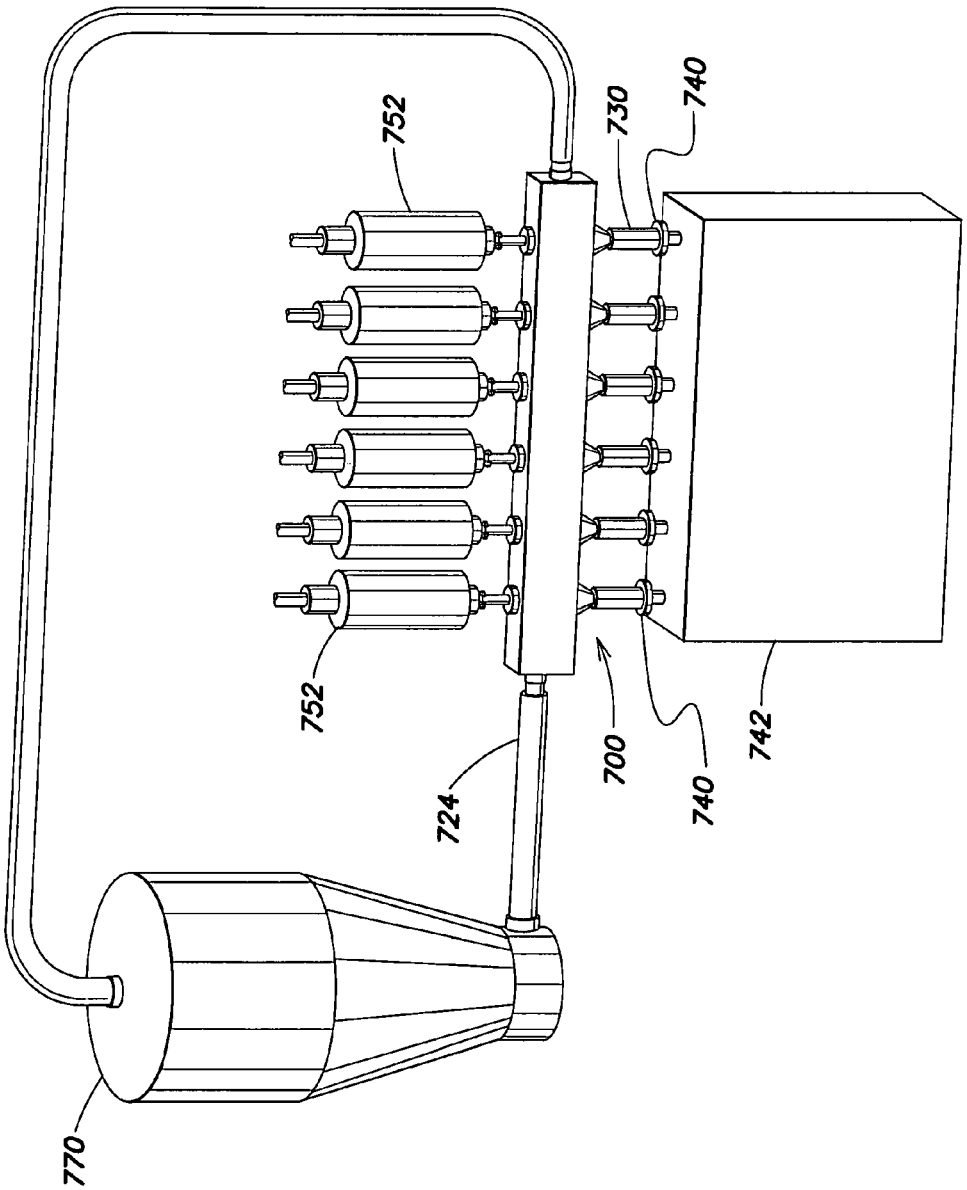

FIG. 25

POWDER DISPENSER MODULES AND POWDER DISPENSER ASSEMBLIES

CROSS REFERENCE TO RELATED APPLICATION

This application is a national stage of PCT/US2009/004500, filed Aug. 5, 2009, which claims priority based on Provisional Application Ser. No. 61/188,001, filed Aug. 5, 2008, which are hereby incorporated by reference in their entirety.

FIELD OF THE INVENTION

This invention relates to methods and apparatus for dispensing and sensing powder and, more particularly, to methods and apparatus for dispensing precisely-controlled quantities of powder into multiple cartridges and for individually sensing the fill state of each of the cartridges. The powder can contain a drug, and the cartridges can be used in an inhaler. However, the invention is not limited to this application.

BACKGROUND OF THE INVENTION

It has been proposed to deliver certain types of drugs to patients by inhalation of a powder as a delivery mechanism. An inhaler having a replaceable cartridge or capsule containing the drug powder is used for drug delivery. The administration of drugs by inhalation typically requires a very small quantity of powder in the inhaler cartridge. By way of example, application of insulin using Technosphere® microparticles can require a dose of as little as 10 milligrams of the powder. In addition, the drug dose must be highly accurate. A dose lower than specified may not have the desired therapeutic effect, while a larger than specified dose can have an adverse effect on the patient. Furthermore, while Technosphere microparticles are highly effective for drug delivery by inhalation, their platelet surface structure causes Technosphere powders to be cohesive and somewhat difficult to handle.

In the commercialization of drug delivery by inhalation, large numbers of cartridges containing the drug must be produced in an efficient and economical manner. An accurate dose of powder must be delivered to each cartridge, and the drug dose in each cartridge must be verified. Manufacturing techniques and equipment should be capable of high throughput to meet demand and should be capable of handling powders which are cohesive and thus do not flow freely. Existing manufacturing techniques and equipment have not been adequate to meet these demands.

International Publication No. WO 2007/061987, published 31 May 2007, discloses systems and methods for simultaneously dispensing precisely-controlled doses of a powder into multiple cartridges. The powder can contain a drug, and the cartridges can be used in inhalers. The fill state of each cartridge, typically the powder weight, is sensed during filling, and powder dispenser modules are individually controlled in response to the sensed weight to insure accurate dosage. The system operates at high speed and can be very compact to enable production filling operations with minimum floor space requirements. Nonetheless, there is a need for improved methods and apparatus for powder dispensing.

SUMMARY OF THE INVENTION

Systems and methods are provided for simultaneously dispensing precisely-controlled doses of a powder into multiple cartridges. The powder can contain a drug, and the cartridges can be used in inhalers. The fill state of each cartridge, typically the powder weight, is sensed during filling, and powder dispenser modules are individually controlled in response to the sensed weight to ensure accurate dosage. The system operates at high speed and can be very compact to enable production filling operations with minimal floor space requirements.

According to a first aspect of the invention, a powder dispenser module comprises: a housing that defines a powder inlet for receiving a powder, a powder outlet, and a conduit connecting the powder inlet and the powder outlet; a feed wand to move powder through the conduit from the powder inlet to the powder outlet, the feed wand including a lower feed element coupled to a first drive shaft and an upper feed element coupled to a second drive shaft; a first actuator coupled to the first drive shaft to rotate the lower feed element; and a second actuator coupled to the second drive shaft to rotate the upper feed element.

According to a second aspect of the invention, a powder dispenser module comprises: a housing that defines a powder inlet for receiving a powder, a powder outlet, and a conduit connecting the powder inlet and the powder outlet; a feed wand assembly to move powder through the conduit from the powder inlet to the powder outlet; a valve to control the powder outlet, wherein the valve includes a valve member that rotates about an axis perpendicular to an axis of the feed wand assembly; and a valve actuator to operate the valve between open and closed positions.

According to a third aspect of the invention, powder dispensing and sensing apparatus comprises: a support structure to receive a cartridge holder configured to hold cartridges; a powder dispenser assembly including powder dispenser modules to dispense powder into the cartridges; a powder transport system to deliver powder to the powder dispenser modules; a sensor module including a plurality of sensor cells to sense respective fill states of each of the cartridges; and a control system to control the powder dispenser modules in response to the respective sensed fill states of each of the cartridges, wherein the control system includes an embedded processor in each of the powder dispenser modules, each embedded processor communicating with a respective sensor cell and elements of the powder dispenser module.

According to a fourth aspect of the invention, a method for dispensing powder into a cartridge comprises: positioning a cartridge under a dispenser module having a conduit containing a powder and a valve at a lower end of the conduit; with the valve closed, operating an upper feed element in the conduit while maintaining a lower feed element stationary; opening the valve; operating the upper feed element and the lower feed element in the conduit to dispense powder through the open valve to the cartridge; and closing the valve when a desired fill state of the cartridge is reached.

According to a fifth aspect of the invention, powder dispensing and sensing apparatus comprises: a support structure to receive a cartridge holder configured to hold at least one row of cartridges; a powder dispenser assembly including powder dispenser modules to dispense powder into respective cartridges in the at least one row of cartridges, wherein the powder dispenser assembly includes an array having one or more rows of powder dispenser modules; a powder transport system to deliver powder to the powder dispenser modules; a sensor module including a plurality of sensor cells to sense respective fill states of each of the cartridges in the at least one row of cartridges; a control system to control the powder dispenser modules in response to the respective sensed fill states of each of the cartridges of the at least one row of

cartridges; and an actuator to move the at least one row of cartridges relative to the array of powder dispenser modules.

According to a sixth aspect of the invention, a powder dispenser module comprises: a housing that defines a powder inlet for receiving a powder, a powder outlet, and a powder chamber connecting to the powder inlet and the powder outlet; a feed wand including a valve element to close the powder outlet and a fluidizing element to fluidize the powder; and an actuator to produce oscillatory movement of the feed wand during dispensing of the powder.

According to a seventh aspect of the invention, a method for dispensing powder into a cartridge comprises: positioning a cartridge under a dispenser module having a powder chamber containing a powder and a valve at the lower end of the powder chamber; opening the valve; dispensing powder through the open valve to the cartridge by oscillatory movement of a feed wand having a fluidizing element in the powder chamber; and closing the valve when a desired fill state of the cartridge is reached.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference is made to the accompanying drawings, which are incorporated herein by reference and in which:

FIG. **1** is a perspective view of a powder dispensing and sensing apparatus in accordance with an embodiment of the invention;

FIG. **2** is an exploded view of the powder dispensing and sensing apparatus of FIG. **1**;

FIG. **3** is a partial vertical cross-sectional view of the powder dispensing and sensing apparatus;

FIG. **3**A is a schematic block diagram of the powder dispensing and sensing apparatus;

FIG. **4** is a perspective view of powder dispenser modules, cartridges, a cartridge tray and weight sensor cells;

FIG. **5** is a perspective view of a powder transport system;

FIG. **6** is a cross-sectional diagram of an array block and one powder transport system;

FIG. **7** is a cross-sectional diagram of a cartridge tray and a tray positioning system;

FIG. **8** is a perspective view of a powder dispenser module in accordance with embodiments of the invention;

FIG. **9** is an exploded view of the powder dispenser module of FIG. **8**;

FIG. **10** illustrates a feed wand used in the powder dispenser module of FIG. **8**;

FIG. **11** is an exploded view of the feed wand of FIG. **10**;

FIG. **12** is an enlarged view of the lower end of the feed wand of FIG. **10**;

FIG. **13** illustrates a feed wand assembly including the feed wand and associated drive components;

FIG. **14**A is a bottom view of the powder dispenser module, showing a fill valve in accordance with embodiments of the invention;

FIG. **14**B is a perspective view of the fill valve of FIG. **14**A;

FIG. **15** is an exploded view of the fill valve of FIG. **14**A;

FIG. **16**A is a top view of a three-spoke granulator in accordance with embodiments of the invention;

FIG. **16**B is a cross-sectional view of the three-spoke granulator of FIG. **16**A;

FIG. **17** is an enlarged perspective view of the lower end of the powder dispenser module of FIGS. **8** and **9**, with some elements omitted and some elements shown as transparent for purposes of illustration;

FIG. **18** is a schematic plan view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **19** is a schematic plan view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **20** is a schematic plan view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **21** is a schematic plan view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **22** is a schematic plan view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **23** is a schematic, cross-sectional view of an array of powder dispenser modules in accordance with embodiments of the invention;

FIG. **24** is an enlarged cross-sectional view of the lower ends of two of the powder dispenser modules shown in FIG. **23**; and

FIG. **25** is a schematic diagram of a powder dispensing and sensing apparatus utilizing the powder dispenser modules shown in FIG. **23**.

DETAILED DESCRIPTION

A powder dispensing and sensing apparatus **10** is shown FIGS. **1**-**7**. A purpose of the apparatus is to dispense powder into multiple cartridges **20** and to sense and control a fill state of each of the cartridges, so that each of the cartridges receives a precisely-controlled quantity of the powder. As used herein, the term "cartridge" refers to any container or capsule that is capable of holding a powder, typically a powder containing a drug substance. As used herein, the term "fill" includes filled and partially filled, since each cartridge is typically not filled to capacity and in fact may be filled to only a small fraction of its capacity. As described below, the apparatus can be used to fill an inhaler cartridge or a compact inhaler, but is not necessarily limited as to the type of container to be filled.

Cartridges **20** can be held in a cartridge tray **22** that is positioned in a tray support frame **24** for processing. The cartridges can be held in an array of rows and columns. In one example, cartridge tray **22** holds forty-eight cartridges **20** in a 6×8 array. The configuration of cartridge tray **22** and the corresponding configuration of apparatus **10** are given by way of example only and are not limiting as to the scope of the invention. It will be understood that cartridge tray **22** can be configured to hold a different number of cartridges and that cartridge tray **22** can have a different array configuration within the scope of the invention. In another embodiment described below, the cartridge tray can hold 192 cartridges. Cartridge tray **22** can be placed in support frame **24** and removed from support frame **24** by a robot.

Components of powder dispensing and sensing apparatus **10**, in addition to tray support frame **24**, include a powder dispenser assembly **30** to dispense powder into cartridges **20**, a powder transport system **32** to deliver powder to powder dispenser assembly **30** and a sensor module **34** to sense a fill state of each of cartridges **20**. Powder dispensing and sensing apparatus **10** further includes a frame **40** for mounting of tray support frame **24**, powder dispenser assembly **30**, powder transport system **32** and sensor module **34**, and actuators **42** to move powder dispenser assembly **30** and powder transport system **32** with respect to cartridges **20**.

Powder dispenser assembly **30** includes an array block **50** having an array of vertical ports **52** and a powder dispenser module **54** mounted in each of the vertical ports of array block **50**. Array block **50** can be configured to match the array of cartridges **20** in cartridge tray **22** or a subset of the cartridges in the cartridge tray. In the above example of a cartridge tray that holds forty-eight cartridges, array block **50** can have a 6×8 array of vertical ports **52** and provides mounting for forty-eight powder dispenser modules **54**. In this embodiment, powder dispenser modules **54** are mounted on one-inch centers. It will be understood that a different spacing arrangement can be utilized within the scope of the invention. As shown in FIG. **8**, array block **50** further includes powder storage and transport channels **60***a*, **60***b*, **60***c*, **60***d*, **60***e*, **60***f*, **60***g* and **60***h*, with one channel for each row of six powder dispenser modules **54** in this embodiment. Powder is delivered by powder transport system **32** to powder dispenser modules **54** through each channel in array block **50**, as described below. Each channel preferably has sufficient volume to store powder for several powder dispensing cycles.

In the embodiment of FIGS. **1-7**, powder transport system **32** includes a first powder transport system **32***a* to deliver powder to a first group of four channels **60***a*, **60***b*, **60***c* and **60***d* in array block **50** and a second powder transport system **32***b* to deliver powder to a second group of four channels **60***e*, **60***f*, **60***g* and **60***h* in array block **50**. Each of powder transport systems **32***a* and **32***b* includes a blower assembly **70** to move a transport gas through the powder transport system, a powder aerator **72** to deliver powder to powder dispenser assembly **30** and a hopper assembly **74** to supply powder to powder aerator **72**. In other embodiments, a single powder transport system or more than two powder transport systems can be utilized.

Blower assembly **70** is coupled through a tube **76** to a gas inlet **78** of powder aerator **72** and produces a flow of transport gas through gas inlet **78**. Powder aerator **72** includes a powder inlet **80** to receive powder from hopper assembly **74**. The powder is delivered by powder aerator **72** through four powder output ports **82** to inlet ends of respective channels in array block **50**. The powder is transported through the respective channels to the powder dispenser modules **54** in each row of powder dispenser assembly **30**. The powder is individually dispensed to cartridges **20** by powder dispenser modules **54** as described below.

Channels **60***a*-**60***h* pass through array block **50**, and a tuned suction manifold **84** is coupled to outlet ends of the channels. The suction manifold **84** of first powder transport system **32***a* is connected to outlet ends of channels **60***a*-**60***d*, and the suction manifold **84** of second powder transport system **32***b* is connected to the outlet ends of channels **60***e*-**60***h*. Suction manifold **84** returns the transport gas to blower assembly **70**, thus forming a closed loop recirculating gas transport system. In other embodiments, the powder transport system can utilize an open loop gas transport system. Any powder not delivered to powder dispenser modules **54** or stored in the channels returns through suction manifold **84** to blower assembly **70**. As discussed below, blower assembly **70**, in some embodiments, can include a gas-particle separation device to retain large powder agglomerates, while small powder agglomerates are recirculated to powder aerator **72** for delivery to powder dispenser assembly **30**. As further discussed below, each powder transport system can include a gas conditioning unit to control the relative humidity and/or temperature of the recirculating transport gas.

The powder transport system **32** can include sensors to determine the powder level in different components of the powder transport system. Hopper assembly **74** can include a hopper level sensor to sense the powder level in the reservoir of hopper assembly **74**. Powder aerator **72** can include a dump valve level sensor to determine the powder level in the dump valve of powder aerator **72**. The blower assembly **70** can include a large agglomerate level sensor. A dispenser fill level sensor can be located at the suction manifold **84** of blower assembly **70**. The powder level sensors can use optical techniques to sense powder level, for example. The powder level sensors can be used to control operation of powder delivery system **32** and loading of powder dispenser modules **54** with powder.

Sensor module **34** can include a sensor housing and an array of sensor assemblies **110** mounted in the sensor housing. In the illustrated embodiment, each of the sensor assemblies **110** includes two sensor cells **114** (FIG. **3**) and associated circuitry. Thus, one sensor assembly **110** is used with two powder dispenser modules **54**. In other embodiments, each sensor assembly can include a single sensor cell or more than two sensor cells. The number of sensor assemblies **110** and the arrangement of sensor assemblies **110** in the array can be such that the sensor cells **114** match the configuration of cartridges **20** in cartridge tray **22** or a subset of the cartridges in the cartridge tray. For the example of a cartridge tray **22** that holds forty-eight cartridges **20** in a 6×8 array on one inch centers, the sensor module **34** can include twenty-four sensor assemblies **110**, which provide forty-eight sensor cells **114** in a 6×8 array on one inch centers. In the embodiment of FIGS. **1-7**, each of the sensor cells **114** is a weight sensor to sense the weight of the powder delivered to the respective cartridge **20**. A weight sensor probe **112** is affixed to each of the sensor cells **114** and contacts a lower end of cartridge **20** through an opening in cartridge tray **22**.

The sensor cells **114** individually sense the fill state of each of cartridges **20** during dispensing of powder, so that powder dispensing can be terminated when the desired amount of powder has been dispensed into each cartridge **20**. The sensor cells **114** are preferably weight sensors which monitor the weight of cartridge **20** during the powder dispensing process and are accurate within 5 to 10 micrograms in the present embodiment. An electrobalance beam is typically used as a weight sensor in applications requiring high accuracy, high speed and repeatability with very small weights.

The physical configuration of the weight sensor assembly **110** is a consideration in systems where powder dispenser modules **54** are closely spaced, such as on one inch centers. Preferably, the weight sensor assemblies **110** can be placed in an array that matches the configuration of cartridge tray **22** and powder dispenser modules **54**. In a preferred embodiment, sensor assemblies **110** have a vertical configuration and two sensor cells **114** are packaged together to form a sensor assembly. The weight sensing mechanical components are located at the top of the assembly, electrical circuitry is located below the mechanical components and an electrical connector is located at the bottom. The sensor assemblies can be mounted in an array for weight sensing on one inch centers.

In another embodiment, a commercially available weight sensor module has a horizontal configuration and can be utilized in a tiered arrangement on three different levels for an array having six cartridges per row. In the tiered arrangement, probes of different lengths are used to contact the cartridges.

The powder dispensing and sensing apparatus **10** has been described as having powder dispenser modules **54** and sensor cells **114** mounted on one inch centers. It will be understood that a larger or smaller spacing between components can be utilized within the scope of the invention. Further, the components of the apparatus **10** are not necessarily mounted in a uniform array. For example, the x-direction spacing between

components can be different from the y-direction spacing between components, or a row of the array can be offset with respect to an adjacent row.

In operation, cartridge tray **22** holding cartridges **20** is positioned in tray support frame **24**, preferably by a robot or other automation mechanism. Cartridge tray **22** is lowered so that cartridges **20** are raised from cartridge tray **22** by weight sensor probes **112** on respective sensor assemblies **110** and are supported by probes **112**. Cartridge tray **22** can be provided with openings at each cartridge location to permit probes **112** to pass through cartridge tray **22** and lift cartridges **20**. Thus, each cartridge **20** can be weighed by one of the sensor cells **114** without interference from cartridge tray **22**. In some embodiments, probe **112** includes a three-point support for cartridge **20**. In other embodiments, probe **112** includes a cylindrical support for cartridge **20**. Powder dispenser assembly **30** is lowered to a dispensing position. In the dispensing position, each powder dispenser module **54** is positioned slightly above and in alignment with one of the cartridges **20**.

As shown in FIG. **2**, frame **40** can include a lower frame **40***a*, a middle frame **40***b* and an upper frame **40***c*. Lower frame **40***a* and middle frame **40***b* are secured to a base plate **41**. Upper frame **40***c* provides mounting for tray support frame **24**, powder dispenser assembly **30** and powder transport system **32**. Array block **50** is connected to actuators **42** and moves upwardly or downwardly when actuators **42** are energized. Sensor module **34** is mounted in a fixed position within lower frame **40***a* and middle frame **40***b*.

Powder transport system **32** can operate continuously or at intervals. The powder dispenser modules **54** are activated to dispense powder to cartridges **20**. The dispensing of powder to cartridges **20** is performed concurrently, so that all cartridges in cartridge tray **22** or a subset of the cartridges in the cartridge tray receive powder simultaneously. As powder dispensing progresses, the weights of cartridges **20** are sensed by respective sensor cells **114**. The output of each sensor cell **114** is coupled to a controller. As discussed below, each controller compares the sensed weight with a target weight which corresponds to the desired quantity of powder. As long as the sensed weight is less than the target weight, powder dispensing continues. When the sensed weight is equal to or greater than the target weight, the controller commands the corresponding powder dispenser module **54** to terminate the powder dispensing operation. If the sensed weight exceeds a maximum allowable weight after the fill cycle, the corresponding cartridge can be marked as defective. Thus, powder dispensing and weight sensing proceed concurrently for a batch of cartridges in cartridge tray **22**. The batch can include all the cartridges in cartridge tray **22** or a subset of the cartridges in the cartridge tray. A powder dispensing cycle can include concurrent dispensing of powder to and weight sensing of a batch of cartridges and achieves 100% inspection and control of powder dispensing.

In one embodiment, the number and spacing of cartridges in cartridge tray **22** matches the number and spacing of powder dispenser modules **54** in apparatus **10**. In other embodiments, the cartridge tray can have a different number of cartridges and a spacing between cartridges that is different from the configuration of powder dispenser modules **54**. For example, the cartridge tray can be configured to hold a multiple of the number of powder dispenser modules **54** and to have a smaller spacing between cartridges than the spacing between powder dispenser modules **54**. By way of example only, the cartridge tray can be configured to hold 192 cartridges **20** spaced on one-half inch centers. With this arrangement, a 12×16 array of cartridges on one-half inch centers occupies the same area as a 6×8 array of cartridges on one inch centers.

As shown in FIG. **7**, the cartridge tray **22** can be displaced in a horizontal direction by a tray positioning mechanism **120** to align different batches of cartridges with powder dispenser modules **54**. Cartridge tray **22** is positioned in tray support frame **24** for processing. Tray positioning mechanism **120** includes an X-direction actuator **230** coupled to tray support frame **24** and a Y-direction actuator **232** coupled to tray support frame **24**. Thus, tray support frame **24** and cartridge tray **22** can be moved in a horizontal X-Y plane for positioning of batches of cartridges in relation to powder dispenser modules **54** and sensor cells **114**.

The cartridge tray with 192 cartridges can be processed as follows. The cartridge tray is moved from a neutral position to a first X-Y position (0,0) such that a first batch of 48 cartridges is vertically aligned with the array of 48 powder dispenser modules **54**. Powder is dispensed into the first batch of cartridges and then the cartridge tray is moved to a second X-Y position (0, 0.5) to align a second batch of 48 cartridges with the array of 48 powder dispenser modules **54**. Powder is dispensed into the second batch of cartridges and then the cartridge tray is moved to a third X-Y position (0.5, 0) to align a third batch of 48 cartridges with the array of 48 powder dispenser modules **54**. The cartridge tray is then moved to a fourth X-Y position (0.5, 0.5) to align a fourth batch of 48 cartridges with the array of 48 powder dispenser modules **54**. Powder is dispensed into the fourth batch of cartridges to complete processing of the 192 cartridges. In the above example, the order of the tray positions and the order of the batches of cartridges can be changed.

It will be understood that this process can be applied to different tray arrangements with a different spacing between cartridges, different numbers of cartridges, and the like. In these embodiments, the cartridge tray is displaced in the horizontal plane to achieve alignment between batches of cartridges and the array of powder dispenser modules. The batch of cartridges typically matches the array of powder dispenser modules **54**. However, in some applications the batch can have fewer cartridges than the number of powder dispenser modules.

Additional details regarding the powder dispensing and sensing apparatus **10** are described in International Publication No. WO 2007/061987, published 31 May 2007, which is hereby incorporated by reference.

Embodiments of powder dispenser module **54** are shown in FIGS. **8-17** and are described below.

Powder dispenser module **54** includes a powder dispenser housing **150** having a lower housing section **150***a*, a middle housing section **150***b*, an upper housing section **150***c* and a cover **150***d*. The powder dispenser housing **150** can have an elongated configuration with a small cross section to permit close spacing in array block **50**. As noted above, powder dispenser modules **54** can be mounted on one inch centers. Middle housing section **150***b* includes powder inlet **130** and a cylindrical conduit that extends downwardly from powder inlet **130** to lower housing section **150***a*. Lower housing section **150***a* includes a tapered conduit that extends downwardly to a dispenser nozzle **158**, which is dimensioned for compatibility with cartridge **20**. The cylindrical conduit and the tapered conduit may be considered to form a powder chamber of the powder dispensing module **54**. Dispenser nozzle **158** is configured to dispense powder into cartridge **20**. The cover **150***d* can be an aluminum cover which is painted black inside to facilitate heat transfer out of the dispenser electronics and to permit the powder dispenser module to be waterproofed.

Powder dispenser module **54** further includes a feed wand assembly **160** to move powder downwardly in a controlled manner through the dispenser to nozzle **158**, and a dispenser fill valve **180** at the lower end of the tapered conduit in lower housing section **150***a*. Powder dispenser module **54** further includes a circuit board **184** having circuitry for controlling feed wand assembly **160** and fill valve **180**, and for communicating with control circuitry that controls operation of powder dispenser module **54**.

Details of feed wand assembly **160** are shown in FIGS. **10-13**. Referring to FIG. **13**, feed wand assembly **160** includes a feed wand **200**, a first actuator **210**, a second actuator **212** and an actuator coupling **214**. Referring to FIGS. **10-12**, feed wand **200** includes an upper feed element **220** affixed to an outer shaft **222** and a lower feed element **230** affixed to an inner shaft **232**. The outer shaft **222** may have a central bore extending through its length, and inner shaft **232** may be concentrically mounted in the bore through outer shaft **222**. Further, inner shaft **232** may be free to rotate within outer shaft **222**.

Ball bearings and drive shaft seals (not shown) are pressed in both flanged ends **222***a* and **222***b* of the cylindrical outer shaft **222**. The ball bearings insure long life and easy rotation of the coaxial inner shaft **232**, and the seals prevent powder ingress, thus insuring long life of the bearings and preventing the drive shaft from jamming, as well as making the system GMP compliant. This is because the seals prevent the powder from accumulating between the drive shafts and thus do not promote bacterial growth. The sealed system is easy to clean, as the entire dispenser module can be submerged in an ultrasonic bath for cleaning.

In some embodiments, upper feed element **220** may be a wire frame structure including a helical portion **220***a* and a straight portion **220***b* located above helical portion **220***a*. Lower feed element **230** may be an auger. In the feed wand **220** of FIGS. **10-12**, upper feed element **220** and lower feed element **230** may rotate in the same direction or in opposite directions, and may rotate at the same speed or at different speeds. Thus, upper feed element **220** and lower feed element **230** may be independently controlled to achieve a desired powder feed operation.

As shown in FIG. **13**, first actuator **210** is coupled to inner shaft **232** for rotation of lower feed element **230**. Second actuator **212** is coupled via actuator coupling **214** to outer shaft **222** for rotation of upper feed element **220**. Actuator coupling **214** may include an upper gear set **240** mounted to second actuator **212**, a coupling rod **242** and a lower gear set **244** mounted to outer shaft **222**. First actuator **210** and second actuator **212** may be miniature motors which can be controlled to independently rotate lower feed element **230** and upper feed element **220**, respectively.

Details of fill valve **180** are shown in FIGS. **14**A, **14**B and **15**. Fill valve **180** is configured as a butterfly valve that is actuated between open and closed positions by a rack and pinion arrangement. Fill valve **180** includes a valve housing **300** having a cylindrical passage **302** that defines dispenser nozzle **158**. A valve member **310** is positioned within cylindrical passage **302** and is connected to a valve shaft **312** which is rotatable about an axis **314**, so that valve member **310** is rotated between open and closed positions. A pinion gear **320** is mounted to shaft **312**, and a rack **322** (FIG. **14**B) engages pinion gear **320**.

A drive shaft **330** is connected between rack **322** and a valve actuator **332**, shown in FIG. **9**. Valve actuator **332** is mounted near the top of powder dispenser module **54** and produces linear motion of drive shaft **330**, which is converted by rack **322** and pinion gear **320** to rotating movement of valve member **310** between open and closed positions. Valve actuator **332** may be a linear solenoid. As shown in FIG. **15**, fill valve **180** further includes bearings **340**, seals **342** and bearing covers **344**.

A gasket may be mounted between the valve housing **300** and the lower housing section **150***a* of the powder dispenser module. The gasket prevents powder from migrating into the valve drive mechanism. The valve member **310** is configured as a disk which rotates 90° between open and closed positions. The edges of the disk are relatively sharp, so that there is no edge for powder to rest on and to fall into cartridges at random times. Such randomly falling powder causes undesirable fill variations. The valve shaft has bearings and seals at both ends to enable easy rotation and to prevent powder ingress. Since the valve drive uses a simple vertical motion, the valve can be closed in 100 to 200 milliseconds, thus overcoming the problem of powder dispensing after the fill command has ended.

The powder dispenser module **54** further includes a granulator **400** shown in FIGS. **16**A and **16**B. The granulator **400** is mounted in the lower housing section **150***a* above fill valve **180** and has an inside wall **410** that is tapered from larger diameter at the top to smaller diameter at the bottom. An orifice element **412** has an inverted conical shape and is configured, in this embodiment, with three radial spokes **414** which support a ring **416**. The spokes define three orifices **420** for discharge of powder through nozzle **158**. The lower edges of the lower feed element **230**, typically in the form of an auger, are angled to match the inverted conical orifice element **412**. A bearing **430** (FIG. **12**) mounted at the lower end of inner shaft **232** engages ring **416** and establishes a desired spacing between lower feed element **230** and orifice element **412**. In operation, lower feed element **230** rotates relative to orifice element **412**, causing powder to be discharged through the orifices **420** in orifice element **412**.

The granulator **400** is mounted above the fill valve **180** and provides rotational support for the lower feed element **230**. The lower feed element **230** rests on a sapphire bearing which is mounted in the ring **416** at the center of the granulator **400**. The granulator **400** is configured to minimize restriction on powder flow. In other embodiments, the granulator may have any number of spokes or may be provided with a pattern of holes, with the parameters of the granulator selected based on the powder being dispensed.

FIG. **17** is an enlarged perspective view of the lower end of the powder dispenser module of FIGS. **8** and **9**, with some elements omitted and some elements transparent for purposes of illustration. FIG. **17** illustrates the interrelationship of lower feed element **230**, granulator **400** and fill valve **180** in the powder dispenser module. In some embodiments, the powder dispenser module can be made GMP compliant by making all parts of the powder dispenser module water-tight.

As discussed above, the powder dispenser module **54** has a cylindrical conduit with a tapered lower section which terminates in the dispenser nozzle. The tapered surface exerts on the powder particles a net upward force which opposes the downward force that is applied to deliver powder through the nozzle. The powder dispenser module shown in FIGS. **8-17** and described above is configured to enhance powder delivery, to reduce powder delivery time and to increase powder delivery accuracy.

As described above, the feed wand assembly **160** is configured with separate drive shafts and actuators for the upper feed element **220** and the lower feed element **230**. By separating the upper feed element and the lower feed element and driving them independently, the upper feed element **220** can rotate continuously with the fill valve closed. This keeps the

powder fluidized and thus ready for dispensing. At the same time, the lower feed element **230** is not rotated, so that the powder between the lower feed element **230** and the fill valve is not compressed. When the powder dispenser module is commanded to dispense powder, the fill valve is opened and the lower feed element **230** is rotated a few revolutions by the first actuator **210**.

The feed wand assembly **160** with separate drive shafts and actuators for the upper and lower feed elements can rotate the upper and lower feed elements in the same or opposite directions and can rotate the upper and lower feed elements at the same or different speeds. Further, one of the feed elements can rotate while the other feed element is held stationary. Thus, the upper and lower feed elements operate independently.

In the powder dispenser module **54**, circuit board **184** may include an embedded processor and motor control electronics. The processor runs a real time preemptive operating system which communicates with its corresponding sensor cell **114** and with the components of the powder dispenser module to control the powder dispenser module.

As described above, the upper feed element **220** can run continuously to keep the powder fluidized in the powder dispenser module. To dispense a required weight of powder, the fill valve is opened and rotation of lower feed element **230** is started for a predetermined time. The powder dispenser module interrogates the sensor cell at fixed time intervals, approximately every 200 milliseconds, and determines a fill rate under the current powder dispensing conditions. Based on the fill rate, the processor modifies the predetermined dispensing time. Since each powder dispensing module communicates directly with its sensor cell, the communications time latency is fixed and a deterministic fill rate is obtained. The powder dispenser module terminates dispensing at the end of the adaptively determined fill time, and the fill valve closes rapidly, preventing overshoot in the weight of the powder dispensed.

The embodiment of the powder dispensing and sensing apparatus **10** shown in FIGS. **1-7** and described above utilizes a two-dimensional array of powder dispensing modules mounted in an array block **50**. In one embodiment, the array block **50** has a 6×8 array of ports for mounting 48powder dispenser modules. In some embodiments, it may be desirable to utilize an array of powder dispenser modules having a single row of powder dispenser modules or a few rows of powder dispenser modules, as shown in FIGS. **18-22** and described below.

An array **500** of powder dispenser modules **510** is shown in FIG. **18**. The array **500** includes a single row of powder dispenser modules **510**. In the array **500**, each of powder dispenser modules **510** receives powder feed **520** on the same side. The array **500** can have any desired number of powder dispenser modules **510**. By providing direct powder feeds to each powder dispenser module **510**, the powder feed mechanism may be simplified. Rows of cartridges to be filled can be indexed into alignment with the array **500** of powder dispenser modules **510** for filling.

An array **530** of powder dispenser modules **510** is shown in FIG. **19**. The array **530** also includes a single row of powder dispenser modules. The array **530** differs from the array **500** of FIG. **18** in that alternate powder dispenser modules **510** receive powder feed **520** from opposite sides. This configuration has an advantage that more space is available for the powder feed mechanism on both sides of array **530**.

An array **550** including a first row **552** and a second row **554** of powder dispenser modules **510** is shown in FIG. **20**. First row **552** receives powder feed **520** from one side, and second row **554** receives powder feed **520** from the opposite side. The array **550** has the advantage of increased powder filling capacity while permitting direct powder feed to each powder dispenser module **510**. Each of rows **552** and **554** can include any number of powder dispenser modules **510**.

An array **560** including a first row **562** and a second row **564** of powder dispenser modules **510** is shown in FIG. **21**. In the array **560**, powder feed **520** is supplied to second row **554** from one side of array **560**, and powder feed **522** is supplied to first row **562** of powder dispenser modules **510** from the powder dispenser modules **510** of second row **564** in a feedthrough manner. An advantage of the array **560** is that powder is supplied to the array from one side, while two rows of powder dispenser modules **510** are used for filling of cartridges at the same time.

An array **580** of powder dispenser modules **510** is shown in FIG. **22**. Array **580** is essentially a repetition of array **560** shown in FIG. **21** and described above, except that upper array **560** receives powder feed **520** from one side and lower array **560** receives powder feed **520** from the opposite side. The array **580** of FIG. **21** has an advantage that a larger number of cartridges can be filled simultaneously, but has the disadvantage that powder feed **520** is more complex than for a single array.

Powder dispenser modules **700** in accordance with additional embodiments of the invention are shown in FIGS. **23-25**. Powder dispenser module **700** includes a powder dispenser housing **710** that defines a powder chamber **712**. Powder chamber **712** extends from a powder inlet **720** to a powder outlet **722**. A lower portion of powder chamber **712** is tapered inwardly toward powder outlet **722**. In the embodiment of FIGS. **23-25**, powder dispenser housing **710** is shown as a block having a plurality of powder chambers **712** for multiple powder dispenser modules. In other embodiments, a separate housing can be provided for each powder dispenser module.

Powder inlet **720** is connected to a powder supply conduit **724** through which powder is supplied to each of the powder dispenser modules **700**. Powder outlet **722** forms a dispenser nozzle for dispensing powder into cartridges **730**. Each of the cartridges **730** rests on a weight sensor cell **740** for sensing the weight of the cartridge **730** during dispensing of powder.

Powder dispenser module **700** further includes a feed wand **750** coupled to an actuator **752**. Feed wand **750** may include a shaft **754** coupled to actuator **752**, a valve element **756** and a fluidizing element **758**. Valve element **756** may be an enlarged portion of shaft **754** that is configured to block powder outlet **722** when valve element **756** is moved to a closed position relative to powder outlet **722**, thereby forming a valve at powder outlet **722**. In particular, valve element **756** may have a conical shape for contact with the periphery of powder outlet **722**. Fluidizing element **758** may be an outwardly extending disk that fluidizes the powder during oscillatory movement of feed wand **750**.

Actuator **752** produces linear movement of shaft **754** between an open position of the valve, as shown in the right side of FIG. **24**, and a closed position, as shown in the left side of FIG. **24**. Actuator **752** also produces oscillatory motion of feed wand **750**, in a direction shown by arrow **760** in FIG. **24**, when the valve is in the open position. The oscillatory motion of fluidizing element **758** causes powder to be fluidized and to be dispensed through powder outlet **722**. After the desired quantity of powder has been dispensed into cartridge **730**, as sensed by weight sensor cell **740**, the feed wand **750** is moved to the closed position of the valve.

As shown in FIG. **25**, a powder transport system **770** may supply powder to an array of powder dispenser modules **700**. The powder transport system **770** may include a blower to

move a transport gas through the powder transport system for delivery of powder to each of the powder dispenser modules **700**. In some embodiments, the powder transport system **770** may operate intermittently to fill each of the powder dispenser modules, followed by one or more powder dispensing cycles wherein powder is dispensed into cartridges **730**. It will be understood that different powder transport systems and different arrays of powder dispenser modules may be utilized within the scope of the present invention. In the embodiment of FIGS. **23-25**, powder dispenser modules **700** dispense powder vertically through powder chambers **712**, and powder is supplied to the powder dispenser modules through a horizontal power supply conduit **724**.

Having thus described several aspects of at least one embodiment of this invention, it is to be appreciated various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description and drawings are by way of example only.

What is claimed is:

1. A powder dispenser module comprising:

a housing that defines a powder inlet for receiving a powder, a powder outlet, and a conduit connecting the powder inlet and the powder outlet;

a feed wand to move powder through the conduit from the powder inlet to the powder outlet, the feed wand including a lower feed element coupled to a first drive shaft and an upper feed element coupled to a second drive shaft;

a fill valve to control the powder outlet;

a valve actuator to operate the fill valve between open and closed positions;

a first actuator coupled to the first drive shaft to rotate the lower feed element;

a second actuator coupled to the second drive shaft to rotate the upper feed element; and

a control system operative to rotate the upper feed element with the valve closed, while maintaining the lower feed element stationary, to open the valve, to rotate the upper feed element and the lower feed element to dispense powder through the open valve to a cartridge, and to close the valve when a desired fill state of the cartridge is reached, wherein the upper feed element and the lower feed element are independently controlled to achieve a desired powder feed operation.

2. A powder dispenser module as defined in claim **1**, wherein the first drive shaft comprises an inner shaft and the second drive shaft comprises an outer shaft concentric with the inner shaft.

3. A powder dispenser module as defined in claim **2**, wherein the feed wand further includes bearings and seals between the inner shaft and the outer shaft, so that the inner shaft is free to rotate relative to the outer shaft.

4. A powder dispenser module as defined in claim **2**, wherein the upper feed element comprises a wire frame and the lower feed element comprises an auger, and wherein the wire frame includes a helical portion and a straight portion above the helical portion.

5. A powder dispenser module as defined in claim **4**, further comprising an orifice element, having at least one orifice, positioned adjacent to the powder outlet and a bearing positioned between the feed wand and the orifice element to define a spacing between the auger and the orifice element, wherein the orifice element comprises a granulator that supports the bearing.

6. A powder dispenser module as defined in claim **5**, wherein the granulator includes spokes that support a ring for receiving the bearing, the spokes defining orifices for dispensing powder.

7. A powder dispenser module as defined in claim **1**,

wherein the valve includes a valve member that rotates about an axis perpendicular to an axis of the feed wand.

8. A powder dispenser module as defined in claim **7**, wherein the valve member comprises a disk mounted for rotation about an axis in the plane of the disk.

9. A powder dispenser module as defined in claim **8**, wherein the disk has a sharp outer edge to limit powder accumulation.

10. Powder dispensing and sensing apparatus including a plurality of powder dispenser modules as defined in claim **1**, and comprising:

a support structure to receive a cartridge holder configured to hold cartridges;

the powder dispenser modules configured to dispense powder into respective cartridges;

a powder transport system to deliver powder to the powder dispenser modules;

a sensor module including a plurality of sensor cells to sense respective fill states of each of the cartridges; and

the control system configured to control the powder dispenser modules in response to the respective sensed fill states of each of the cartridges, wherein the control system includes an embedded processor in each of the powder dispenser modules, each embedded processor communicating with a respective sensor cell and elements of the powder dispenser module.

11. A method for dispensing powder into a cartridge, comprising:

positioning a cartridge under a dispenser module having a conduit containing a powder and a valve at a lower end of the conduit;

with the valve closed, operating an upper feed element in the conduit while maintaining a lower feed element stationary;

opening the valve;

operating the upper feed element and the lower feed element in the conduit to dispense powder through the open valve to the cartridge; and

closing the valve when a desired fill state of the cartridge is reached.

12. Powder dispensing and sensing apparatus including a plurality of powder dispenser modules as defined in claim **1**, and comprising:

a support structure to receive a cartridge holder configured to hold at least one row of cartridges;

a powder dispenser assembly including the powder dispenser modules to dispense powder into respective cartridges in the at least one row of cartridges, wherein the powder dispenser assembly includes an array having only one or two rows of the powder dispenser modules, wherein direct powder feeds are provided to each powder dispenser module of the one or two rows of the powder dispenser modules;

a powder transport system to deliver powder to the powder dispenser modules;

a sensor module including a plurality of sensor cells to sense respective fill states of each of the cartridges in the at least one row of cartridges;

a control system to control the powder dispenser modules in response to the respective sensed fill states of each of the cartridges of the at least one row of cartridges; and

an actuator to move the at least one row of cartridges relative to the array of powder dispenser modules.

13. Powder dispensing and sensing apparatus as defined in claim **12**, wherein the array of powder dispenser modules comprises a single row of powder dispenser modules.

14. Powder dispensing and sensing apparatus as defined in claim **13**, wherein the powder transport system is configured to individually deliver powder to each of the powder dispenser modules of the single row of powder dispenser modules.

15. Powder dispensing and sensing apparatus as defined in claim **12**, wherein the array of powder dispenser modules comprises two rows of powder dispenser modules.

16. Powder dispensing and sensing apparatus incorporating one or more powder dispenser modules as defined in claim **1**.

17. Powder dispensing and sensing apparatus as defined in claim **16**, comprising:

a support structure to hold a plurality of cartridges;

the powder dispenser modules configured to dispense powder into respective cartridges;

a powder transport system to deliver powder to the powder dispenser modules;

a sensor module including a plurality of sensor cells to sense respective fill states of each of the cartridges; and

the control system configured to control the powder dispenser modules in response to the respective sensed fill states of each of the cartridges.

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